April 2013: https://www.researchgate.net/publication/295667275
DOI: 10.13140/RG.2.1.1479.6569

Theoretical review (monograph length) = integrated draft of Parts 1-3 of HaMW

Titles

How a mind works. I. Historical and methodological roots of a fundamental theory

How a mind works. II. A fundamental theory of the individual's action, perception, emotion and thought

How a mind works. III. Development of an acculturated and embodied human life

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Author's footnote

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The development of this approach depended on theoretical contributions from Mark Conner, Richard Freeman and Oliver Sharpe. Programs for analysis of data were developed also by Jeff Brunstrom and Rosemary Platts. Other colleagues and students who collected and/or analyzed key data included Anne Thompson, Behnaz Shahedian, Richard Griffiths, Lourdes Santos, Nicola Richardson-Harman, Tim Earl, Sirous Mobini, Harry R. Kissileff, Melanie Konle, Jennifer Schneider, Clare Wainwright, Liz Gulliford, Lee Shepherd, Abigail Han and Christina Brown.

The first version of this exposition was distributed in 2009. The present version was rearranged into three parts of approximately equal length for presentation as a set of normal-length papers if necessary, and the literature citations updated to 2012. Neither the overall length nor the style of exposition is acceptable to any of the relevant review journals. Hence different parts of the paper are being rewritten in styles which are familiar to readerships of appropriate journals and compatible with present editorial policy, with references updated to 2016 and expanded in range to include the increasingly rapid publication of relevant evidence.

Abstract (for the combined three Parts)

This paper presents the simplest known theory of processes involved in a person's unconscious and conscious achievements such as intending, perceiving, reacting and thinking. The basic principle is that an individual has mental states which possess quantitative causal powers and are susceptible to influences from other mental states. Mental performance discriminates the present level of a situational feature from its level in an individually acquired, multiple featured norm (exemplar, template, standard). The effect on output of a moderate disparity between input and norm is scaled in a universal unit of discrimination (Weber's fraction), with the norm's level being zero. When one process converts separate sources of input into an output, their discriminative distances from norm are summated. Distinct processes converging on an output combine their discriminations from norm orthogonally. An output may be influenced by other outputs as well as by inputs. Descriptive performance is the influence of one category of input on a verbal output. Reasoning is minimally the effect of one verbal process on another. In deeper mental processing, the influence on a response comes from a concept modulating a description: this process gives the meaning to an emotion or a motive. Descriptive modulation of stimulation corresponds to a bodily sensation or other conceptualized percept. When an output is explained solely by sources of input, that response to the stimulation may be mediated unconsciously. Development of a person within physical and communal environments embodies such mental causation within material causation and acculturates that mind to social causation.

Keywords: personal cognition, mental causation, discrimination scaling, representational templates,

Part One

How a mind works.
I. Historical and methodological roots of a fundamental theory

Abstract
An innovative theory of how an individual's mind works can be rooted in the first quantitative psychological discovery, made in the early 1840s. E.H. Weber found that the minimum distinguishable increase in strength of a physical stimulus was constant fraction over a wide range of medium strengths. That result was extended by him and others to many sensory modalities. Yet it was grossly misunderstood by Fechner (1960) and by non-psychologists and some psychologists to this day, as a way of connecting contents of consciousness such as sensations to the material universe. In fact, Weber's finding provides a means of measuring the mental processes that account for an individual's psychological performance, including the highly sophisticated achievement of awareness. Weber's fraction provides a universal unit of measurement of the distances of variants of a situation from the structured standard that the individual brings to a particular occasion as they affect the individual's actions and reactions at the time.

General Introduction

The thesis of this three-part paper is that each mind is a determinate causal system, normally having a capacity to act from reason. This re-entrant network of mental causation is distinct from causal systems in the environment, either material or societal. Yet an individual's mind develops from both the biological universe and the social universe, and that embodied and acculturated system lives on while grounded in physicality and symbolic culture. The paper expounds the simplest logic yet proposed for understanding how such a mind works, consciously and unconsciously.

Each elemental causal process within a mind transforms its incoming pattern directly into its outgoing pattern. Perceptual performance extracts its mental input patterns from the environment. Intentional performance covers that environment with its mental output patterns. In contrast, the outputs from perception and the inputs to intention are covert, influencing and influenced by other processing around the causal network of that mind. At least some of these covert input/output functions and their interactions can be characterized by calculations from observed social and material sources of information for perception (stimuli) and sinks of information for intention (responses). The second paper in this series of three on how a mind works specifies the straightforward but extensive arithmetic required. Hypotheses from such a theory can be tested against appropriately designed accumulation of observations in particular situations, with or without experimental intervention.

The calculations start by relating the observed levels of each distinct environmental sink and source in the individual's present situation. In experimental psychology, these overt response/stimulus relationships are familiar from factorial analysis of variance and psychophysical functions, for example. In observational multivariate research, they correspond to the hypothetical paths between measurement variables in structural modeling (Pearl, 2000). With categorical rather than quantitative sources, these overt functions have affinities to conjoint analysis (Luce & Tukey, 1964) and item response theory (cp. van der Maas, Molenaar, Maris *et al*., 2011).

However, those other designs and analyses combine data across individuals and sessions. The present approach treats seriously each response/stimulus data pair as it is generated by an individual in a specific situation. Furthermore, these calculations exhaust the interpretative potential of the completed set of data for that individual's session. The best fitting hypothesis characterises the dynamic structure of the mental causation by which the individual has dealt with the situation as tested. Generalisation across individuals and/or situations is based on the performance characteristics measured by these models of situated personal cognition.

This radically individualized approach to psychology provides the most basic theory and method available for the study of mental achievements of all kinds by embodied and acculturated systems, natural or artificial. It is a foundation for fully specified theories of human action, reaction, attention, perception, memory, thought, and the comprehension of linguistic and other communications.

Discrimination from personal norm

Weber's discovery

The reputedly first major finding in experimental psychology was reported by E. H. Weber in 1834 (Ross & Murray, 1996). Weber measured the minimum distinguishable fraction of pressure from a weight or of distance between two points on the skin. He found the fraction to be approximately constant at moderate pressures or distances. Constancy of Weber's fraction in medium ranges was replicated by Weber and many others across the sensory modalities. Hence the finding is not only robust; it is also very general. Weber's fraction should be regarded as a foundational discovery of psychological science. Unfortunately, however, the principle was misunderstood and misused almost from the start. The approach expounded in this paper rescues the Weber fraction, to put it at the cornerstone of measurement of the dynamic structure of an individual's mental processing.

For millennia, the distinction between a person's mental life (the psyche or personal soul) and that person's bodily life, and also social life, has been assumed by most thinkers to be between the contents of consciousness and the material universe, and/or between awareness of self-identity and of societal institutions and culture. Nevertheless, it has also long been recognised that some mental processes are irretrievably unconscious, such as the implicit pattern-translating processes required for achievements like remembering the public past, articulating comprehensible speech, and perceiving colour. Yet to this day, some parts of psychology fail to distinguish between such objective mental performance and the subjectively experienced phenomenology (which itself can also be treated as an achievement). In related academic disciplines, such as philosophy of mind, integrative neuroscience and social anthropology, the subject matter of psychology has almost universally been considered to be limited to the conscious mind.

Weber himself appears not to have been clear that he was measuring discriminative performance. His name for the observed fraction was a "just noticeable difference" (Weber, 1834/1996). This concept of noticing a difference can be understood to presuppose the awareness of two intensities of a private sensation. That subjectivist interpretation of Weber's fraction was taken up by G. T. Fechner as a means of building a bridge between the material world that stimulates the senses and a mental world that each of us experiences. In contrast, the present paper takes the experiencing or not of a particular sensation as an issue requiring additional evidence (as illustrated in the section on types of mental process).

Fechner (1860) proposed that intensities of sensation were equivalent to concatenations of Weber's fraction, which he claimed yielded a logarithmic scale. His logic is subject to many criticisms (Luce & Edwards, 1958). The point that concerns us here, though, is that the claim flew in the face of Weber's discovery that the minimum discriminated fraction increased at both low and high levels of physical stimulation. In the present approach, the working principle that discriminative acuity is at a constant fraction is applied only to moderate ranges of sensory stimulation. Furthermore, the zero of that scale of discriminated disparities is found to be within the range of physical stimulation in which Weber's fraction is constant. Hence it is irrelevant that logarithmic values lack a finite point for zero quantity.

Fechner's implicit personal norm

Fechner (1860) converted the theoretical concatenation of fractions into an equation that related judgments of strength of stimulation to the logarithm of physical quantities of the stimulus. That is, when Weber's minimum (increasing) fraction from stimulus level S_O to level S_N is expressed as $(S_N – S_O) / S_O$ for a quantitative response R_N, Fechner's equation is $R_N = k.\log S_N + c$. Only the varied levels of response and stimulus appear in the equation. It does not include the value of a basal level of stimulation (S_O), nor the sizes of the responses (R_O) to samples of that presumed constant stimulus. Yet the equation is interpreted as observed responses (R_N) that judge the degree of difference of each presented sample of the varied stimulus (S_N) from the same standard stimulus (S_O). Hence, considered as a measure of discriminative performance, Fechner's semi-logarithmic equation presupposes a fully functional standard held in the participant's mind from before the first test stimulus, and maintained throughout the session that provided the data captured by the equation.

Thurstone (1927a,b) made this presupposition explicit in his principle and methods of comparison to a standard. In a common procedure for measuring discriminative acuity, each sample of one of the varied levels of the stimulus is presented alongside a sample of a constant stimulus, unidentified as such. The participant is instructed to respond with a comparison between the two samples after examining each. Responses to the samples of the standard by itself are not required by Thurstonian analyses or in the calculation of Weber's fraction (Torgerson, 1958).

The investigator might endeavour to set a standard level of stimulation by presenting an identified modulus before the first test sample. Yet that setting would have to be remembered exactly throughout the session if Fechner's equation (or any other psychophysical 'law') is to be valid for the judgments performed on the varied stimuli. Hence it was proposed instead that each participant's own well established, long-term memory be explicitly invoked in each quantitative judgment on a test stimulus, in a series in which levels are kept within the range of constancy of Weber's fraction (Booth, Thompson & Shahedian, 1983; compare McBride, 1983). Even without such an experimental design, participants can construct remarkably precise and stable implicit standards or norms from the initial test stimuli (e.g., Barsalou, 1985; Morgan, Watamaniuk & McKee, 2000; Nachmias, 2006; Stewart, Brown & Chater, 2005).

An initial explicit standard might help to fine-tune that construction from long-term memory (Mobini, Platts & Booth, 2011; also see Conner, Booth, Clifton & Griffiths, 1988a). Indeed, learning from scratch is unlikely to occur unless the test situation is so artificial that exposure in life is of no use in carrying out the task (Stewart *et al*., 2005). In other words, working memory and perception are thoroughly interdependent (see, for example: Gao, Gao, Li *et al*., 2011; Pan, Cheng & Luo, 2012; Soto, Heinke, Humphreys & Blanco, 2005). Indeed, such learning is a logical prerequisite of any functional interaction with a changing environment. During development, categories of entity in the environment and also of each entity's features have to be constructed from physical and social input and output. In other words, the multiple-featured norms are dynamically stable templates acquired by personal experience of exemplars to date.

The participant's own implicit standard is also presupposed by modern theory of detecting minimum strengths of stimulation (Tanner, Wilson & Swets, 1954). In accord with Thurstone (1927a), the participant in a detection experiment is provided with unidentified samples of the constant stimulus of background noise as well as samples of varied levels of the stimulation under test. Nevertheless, at the moment that the test sample is present and being judged for presence or absence of the stimulus, the participant must operate with a previously acquired construct of the presence of noise alone. With some sorts of stimuli, it may be feasible to receive two signals simultaneously. Nevertheless many successful comparisons are made between successive momentary presentations. Indeed, some common experimental designs preclude simultaneous inspection of the two stimuli.

Detection tasks are widely used, even when discrimination from norm is data-analytically more efficient (Macmillan & Creelman, 2008). Furthermore, detection of the presence of a stimulus (or 'absolute threshold') may not even be relevant in daily life except as the indicator of a potential emergency. The quantity of a stimulus usually matters much more than merely its presence. Discrimination is as validly and reliably measured as detection is, if the method takes account of the functional situation (Curio, 1994).

Discrimination between the personal norm and the test situation

The feature's level in the learned norm

The internal standard required for performance on a psychophysical function is brought to centre stage by this paper's theory of personal cognition and behaviour. The presupposition is that each participant has already acquired a template or norm for the situation that is simulated by the investigator's design of the session of tests. Hence the norm has a particular level of each learned feature of the situation. The level in the norm is compared with the level at each test in which that feature is salient, whether or not a feature is verbally conceptualized in the responses to the tested samples. This approach unites the apparently rival theories of recognition of an object by matching to a template or by integrating the object's features (Booth, 1994b; Booth & Freeman, 1993). It is the psychophysical (response/stimulus) version of one psychometric (response patterning) theory of object category recognition (Nosofsky, 1986). A theory of reference points has also been deployed to explain dependence of the speed of comparison on the match between criterion concept and the range of stimuli (Holyoak, 1978).

The pure stimulus classically used in psychophysics is assumed to be assimilated to a feature of a previously experienced situation. Those familiar situations have other categories of feature which the test stimuli lack or have at fixed levels. Thus a pure solution of sugar might be assessed as though it were poorly flavored lemonade. A looming circle may be processed much like an approaching motor vehicle. A loud roar might be perceived as the noise of a jumbo jet overhead, coming down to land. A volatile compound can be given a culturally established name if the levels of stimulation of several olfactory receptors are sufficiently similar to those stimulated by the mixture of compounds released into the air by a familiar flower, food or other material having a distinctive smell (cp. Stevenson & Boakes, 2003; Stevenson, Case & Boakes, 2005).

On this theory, the linear Weber-Fechner function of response on stimulus arises from objective judgments of disparities between the tested levels of the stimulus feature and its level in the norm. If judgments have indeed been anchored on the familiar version of the test situation, the standard level of a feature category can be determined by interpolating to the stimulus value for the central tendency of responses at that anchor point (Booth *et al.*, 1983; Conner, Land & Booth, 1987).

Discrimination distances from norm

The final step in calculating each response-stimulus function is to convert the stimulus scale into number of Weber fractions below or above the norm level. This maps the achievement of the participant's quantitative response to each stimulus sample onto a point at a distance from the norm in a universal unit of discrimination. Categorically distinct response-stimulus functions can then be related directly to each other, despite the diverse scales of measurement of levels of the stimuli and any variations in the format required for responses.

This scaling of each sample on a distance from the norm squeezes every last drop of causally relevant information from each observed data-pair. The samples' distances from norm measure the complete and exact content of the information extracted from the stimulus and emitted by the response. That contrasts with purely probabilistic characterisation in its various forms: those derivations measure only the amount of information processed.

Hence norm-zeroed discrimination scaling starts to fill a huge gap in basic theory of information. The unit of information, a ‘bit’, measures only the quantity of information transmitted, as emphasised from the start (Shannon & Weaver, 1949). Bits capture nothing of the content and qualitative structure of the information conveyed in the transmission. In contrast, discriminations from norm include all the particulars of the patterns of input and output for the mental process. Furthermore, relationships between response/stimulus functions provide evidence on the structure of the information that the environment has afforded to the norm. A minimum set of those content-measuring relationships is specified from first principles later in this paper, in the sections on types of elemental causal function and interactions among them.

Each feature’s context of other features

Contextualized disparities from norm

Each observed response-stimulus relationship can be scaled in discrimination distances from norm. However, for many responses, a situation and its norm are liable to have multiple stimulus features. Therefore the scale for any one feature has to be considered from the start in the context of other features’ scales from the same norm. This issue can be addressed for the case of only one additional feature, because that account can be generalized to any number of contextual features.

The observed data to which one response-stimulus function has been fitted may be statistically independent of (uncorrelated with) the data for the function of that response on another stimulus. In that case, the two functions are at right angles in a two-dimensional stimulus space (e.g., in the plane of the x and z axes), intersecting at the norm point for each stimulus. When the observed values of the response at each stimulus are plotted perpendicularly to the plane of the two stimuli (i.e., parallel to the y axis), every observed data pair occupies a point on the surface of one of two cones, which are set vertex to vertex at the norm point ($y = 0$).

Data-pairs with stimulus values on one side of the norm are on a different cone from data-pairs on the other side. In order to include all data on the surface of one cone, each response-stimulus line has to be folded at the norm point, i.e. plotted as absolute (unsigned) values of the response, either all above the norm response or all below it. The mathematical convention that absolute values are expressed as positive would produce a two-stimulus response cone resting on its vertex. In science, however, the maximum or the best value is generally plotted at the top of the graph. For example, peaked plots of psychophysical functions are commonplace in work on learned similarities between stimuli (Hovland, 1937; Shepard, 1958, 1965) and sensory preferences (Beebe-Center, 1932). Hence, for present purposes, folded response values are given a negative sign for stimulus values above the norm point as well as below it. That gives a cone suspended from its vertex.[1]

[1]There is no precise base to the cone of discriminations from norm. The folded linearity should break down when Weber’s fraction starts to increase or when responses go too far beyond an anchor on a familiar point away from the norm. *Figure X could be cited hereabouts (page 120 of this manuscript).*

Stimulus values in units of Weber's fraction remain positive above the norm, as well as negative below it, since the norm value is zero for each stimulus feature as well as for the response. In contrast, the distance along the stimulus plane from the norm for the two stimuli (X_0, Z_0) to a pair of observed values of the stimuli (X_k, Z_k) is always on one side of zero, because the signed distances are squared in the formula for a point on the surface of the cone in the plane of the response value, $(X_k^2 + Z_k^2)^{0.5}$ in accord with Pythagoras's theorem.

Both summation along one stimulus axis and also the square root of the sum of the squares of the distances along each stimulus axis are arithmetical operations that generalise to three or more stimuli. That is because Pythagoras's theorem applies to the diagonals of a cube, and so on. Hence the cone for two stimuli that influence a response generalises for three or more stimuli to a 'hyper-cone' that cannot be visualised.

Contextual features that depart from norm

When the mean of the observed discrimination-scaled stimulus values for one of two stimuli is at the norm, the function for the other stimulus will peak on that zero point at the vertex of the cone, thus forming an isosceles triangle. However, a session's mean value for one of the stimuli might be some way from the norm. That is a defect in that feature of the context. In such cases, the plane of the other peaked function is displaced. Its data fit the edge of a vertical cut through the cone at some distance from its vertex (Booth & Freeman, 1993). Hence that function's peak is rounded to a level lower than the norm on the response axis. In other words, even a sample having a measured level at the norm is not evaluated overall as being at or very near to the norm.

This conic section, parallel to the axis for the response, is one branch of a hyperbola, $(x^2 - y^2)/k = 1$ (Figure 1). The asymptotic tangents to the hyperbola intersect at its vertex -- namely, the apex of the isosceles triangle through the norm (cp. the straight lines in Figure 1). The (y,x) coordinates of the vertex of the hyperbola fitted to a session's data provide an estimate of the mean of the presented values of the contextual stimulus, both in stimulus discrimination units (x axis) below or above the norm and in response units (y axis).

Figure 1 about here

Samples with moderate contextual defects do not affect the calculations seriously if there are adequate numbers of data further from the norm (within the range of constancy in Weber's fraction). The slope and error of the regression line which go into the calculation of the discriminative acuity, and of the norm that was used while discriminating, are largely determined by the more extreme strengths of the stimulus, as follows from the use of squared deviates.

The distance of a test stimulus from the learned level was dubbed a generalisation gradient by behaviorists (Hovland, 1937; Hull, 1947). The strength of the learned response decreases at stimulus levels below and above that of the trained cue. An early proposal for the shape of this peak was a hyperbolic function (Pierrel, 1958). The simpler isosceles triangle was widely recognized, at least as an approximation (Blough, 1967; Shepard, 1965). A peaked function is implicit in any acquired matching process, such in unreinforced familiarisation (Gati & Ben-Shakhar, 1990) and attitude scaling (Andrich, 1988).

The hyperbola to which discrimination-scaled data should be fitted differs from the quadratic equation fitted by the traditional folding of preference data (Coombs, 1964). It also differs from the orthogonal contrasts used in factorial analysis of variance. The quadratic is the first (after linear) in the set of polynomial terms that are an accepted way to summarize the numbers collected when there is no specific theory on which to base a substantive measurement. In statistical folding, e.g. non-metric multidimensional preference analysis (Carroll, 1972), even the direction of the inflection (peak or trough) comes solely from fitting the data, however collected. A fully scientific approach fits the observations made in an appropriate design to an equation determined by a mechanistic theory, such as discrimination from a contextualised norm.

The importance of fitting to the hyperbola had an early illustration in an individual whose data for each of two features of the object appeared to fit an unfolded quadratic equation with a peak far below the norm (Figure 2, upper panel, redrawn from Booth, 1994a, Figure 5.3). This person was taking part in an experiment on the effects of levels of sucrose and citric acid on liking for a vended drink containing orange flavouring. The apparent contextual defect encouraged a guess that the participant was using orange juice as the norm for comparison. The real juice has a visual and tactile texture very different from that of the orangey flavoured drink with no fruit particles in it. Nevertheless when the data were fitted to the theoretical hyperbola, the contextual defect turned out to be rather small (Figure 2, lower panel). Apparently, the participant's familiarity with the vended drink was sufficient to distract the largely taste-driven judgments away from the textural divergences from juiced fruit.

Figure 2 about here

This mechanism of contextual defects is consistent with the theory of the sharply triangular norm-zeroed psychophysical function (Booth *et al*., 1983), while offering a mathematically exact account of observations of rounded peaks (e.g., Shepherd, Farleigh & Land, 1984).

Learned contextual dependencies

Invocations of context are often underspecified. That speculative vagueness is removed by treating responses as the discrimination of the situation from a learned norm having multiple features. The power of this norm, and its limits, are central to the interdependence of ongoing perception and long-term memory. Previously acquired constructions that are crucial to effective current processing are retrieved into working memory. This does not mean that rehearsal is necessary to sustain perception. The executive processes in working memory and perception could be entirely subconscious. Indeed, it is likely that implicit conceptual processes are inherent to perceptual processes at all levels, neural (e.g., King, Korb & Egner, 2012), linguistic (e.g., Wright, 2012) and mental (norm-zeroed discrimination).

The gist of a communication depends on the context and the observer (Brainerd, Reyna & Ceci, 2008). A more precise specification of gist would be an interpretation of the explicit signal in terms of the full norm currently developed in memory. Analysis of semantic memory in terms of gist exploits 'fuzzy logic', which has values between true and false (Brainerd & Ryena, 1990; Reyna, 2012). Those undefined intermediate truth values can be replaced by the data-specified norm-zeroed scale between the perceived absence of a feature and its unequivocal presence at varied levels.

Categorisation of simple visual objects provides highly specific examples of contextual features. Rectangles moving together and then apart appear to bounce off each other when there is high contrast between the visual objects and the background (Caplovitz, Shapiro & Stroud, 2011). When the figure-ground contrast is low, one rectangle appears to continue its motion across the field ('streaming'). The contrast can be in luminance or hue (Caplovitz *et al*., 2011). Hence, the rectangular shape is not the controlling feature but rather the contrasts at its edges before and after contact. Such effects are theoretically assimilated to feature differences in the account of context provided by norm-zeroed discrimination.

These examples illustrate the importance of quantitative characterisation of the operative features, not just specifying the experimental manipulations. This becomes crucial when interactions between features are considered: the determinate norm and discrimination scale for each feature avoid the loose parameters that plague the modelling of patterns in responses alone (see later section on Interactions).

Ecological validity of context

Finally, norm-zeroed discrimination scaling of contextual defects provides a quantitative basis for judging the ecological validity of an experiment as representative of real life (Brunswik, 1955, 1956). The degree of invalidity can be measured in units of the scoring of a response or in number of Weber fractions on an observed or integrated stimulus dimension. Large contextual defects are liable to be underestimated because some features were sampled outside the range of constancy of Weber's fraction.

The basics of psychological measurement

Psychological *versus* social and material quantities

Independence of psychological measurement

The measurement of a mental process should not be forced into a model of physical measurement, nor abandoned to arbitrary fiat or tradition about the use of numbers. When combined with subjectivism about the mind, such approaches have led some to the conclusion that measurement is impossible in psychology. Strengths of a sensation or other private experience cannot be concatenated observably, as physical lengths or masses can be. There can be no socially agreed standard of a subjective magnitude, unlike a unit of currency or the date of a public holiday. Mere instructions to respond in ratios of a number assigned to an initial sample may or may not put experienced intensities onto an equal-ratio scale.

Psychological measurement is entirely distinct from both physical and social measurement. Its fundamental validity is assured by conjoint design with analysis by double cancellation (Luce & Tukey, 1964). However, such resort to abstract first principles demands amounts of data that are prohibitively large for most investigations of substantive issues. Also, fundamental measurement on multiple dimensions risks ecologically implausible combinations of extremes.

The linearity of an individual's responding on a self-provided category can be assured by much simpler procedures than conjoint cancellation (Shapiro, 1961). That technique of personal scaling can be extended to several self-generated levels on an effectively linear psychological scale (Singh & Bilsbury, 1989a,b). However, those approaches are limited to measurement of a single construct at a time. They are also much more laborious than quantitative judgments.

Norm-zeroed discrimination provides a theoretical foundation for designs that yield an unusually high ratio of complexity and precision of interpretation to number of raw data. In psychology as in the natural and social sciences, sound and practical measurement requires empirically concrete theory, not just abstract theorems.

The ordinary skill of quantitative judgment

Remarkably little attention has been given to the strategy of trusting participants to judge quantities validly. There seems to be an underlying presumption that people generally are capable only of selecting among a few boxes with a short phrase against each. Even worse, the responses are assumed to measure what the investigators think is meant by the words they provided. There is no examination of the constructs that the raters used, as is routine for the specificity of any physical measurement procedure. Equally erroneously, the ranks of the verbal categories are treated as normally distributed quantities, instead of putting the incidences of ticks on each box into frequency statistics as competent survey analysts do.

These fallacies are perpetuated by calling a response line an analogue, or a numerical score the estimate of a subjective magnitude. Mistakes of that sort are not avoided by merely naming a layout after a previous investigator such as Likert or with a widely used but erroneous label such as VAS ('visual analogue scale'). Investigators are reduced to the ridiculous procedure of using a ruler to measure the distance of each response along the line from an end anchor. The multiple anchored 'scales' seldom bear any relation to the original two or three grades of extreme or moderate agreement or disagreement with a single statement of attitude in the layout used by Likert (1932), for the totally different purpose of obtaining scores for use in multi-item psychometric scaling. These errors have even been combined, by placing ordered categories on a line at positions spaced according to numerical ratings that were collected under different conditions and averaged across groups regardless of differences between individuals.

In contrast, the evidence is that the ability to make quantitative use of single-digit integers higher than three can be acquired in early childhood within any human culture (Cantlon, Safford & Brannon, 2010; Dahaene, Izard, Spelke & Pica, 2008; Nunez, 2011). Most quantitative judgments make no more than about five or seven discriminations (Conner, Haddon, Pickering & Booth, 1988c; cp. Miller, 1956) because of the memory load required (Baddeley, 1994). This skill of judging quantities that are public, such as distance, duration, weight and concentration, can readily be extended to private quantities such as the extent of a pain or a joy, particularly when raters' own words are used to express their phenomenology (e.g. Booth, O'Leary *et al*., 2011; Bowman, Booth, Platts *et al*., 2004; Conner, Haddon & Booth, under review; Freeman and Booth, under review).

Hence there are good grounds for expecting any set of appropriately elicited quantitative responses to arise from a linear response-stimulus function. The consequences of treating each individual's performance as linear in this way are then open to empirical examination in each type of investigation. Ideally, linear competence should be checked in each individual in each session. Norm-zeroed discrimination in principle offers such routine checks.

The above considerations point to a single type of layout for responses to be analysed as quantitative judgments. The participant is asked to place each test stimulus at a position on a line, or in a row of single-digit integers, with just two positions anchored verbally or pictorially. This procedure frees the ratings from the complicated instructions and biased selections of stimuli that have become traditional because of investigators' misconceptions of 'scaling'. If the generated judgments have a straight-line relationship to the presented quantities (or to a simple transformation of them), there is no need for mathematical justification of the claim to have measured some psychological process that transforms stimulus quantities into response quantities. A complete explanation of the linearity is provided by that theory that responses are at discrimination-scaled distances from the personal norm for the tested situation, as follows.

The universal layout for quantitative judgments

Judgments of the stimulus

Whether expressed numerically or graphically, judgments are perceptual achievements. They estimate the objective magnitudes in the environment, not subjective states of sensation, emotion or desire. If the observed positions on lines or in the number series are analogues of anything, it is objective distance, but in a sense that encompasses either physical kilometres or social closeness of kinship.

The linear array

The theory of personal cognition relies on the repeatedly tested working principle that quantitative judgments place test stimuli at distances from the norm. This psychological scale has the norm at zero and both interval and ratio properties over the range of constancy of the Weber fraction. It follows that quantitative judgments should be elicited as responses placed on a linear array, whether graphic or numerical.

The response can be a position on a continuous or broken line, a row of boxes, or some or all of the series of single-digit integers from zero. Score out of ten (with a zero) is routine for the many viewers of talent shows. These eleven (unlabeled) digits are amply sufficient; just 0 to 4, i.e. quarters of a whole, serve for many purposes (Friedman & Friedman, 1986). For those who regularly think in percentages, 0 to 100 can be used as a numerical response (Booth, Mather & Fuller, 1982), or the eleven 10% points (and maybe 5%s as well) in a graphic array for a positional response.

Just two anchors

Two points are logically necessary and sufficient to specify a straight line. Three anchors carry the risk of generating two different slopes, i.e. unequal discrimination distances between the middle anchor and either outer anchor. Multiple anchors have long been known to have uneven spacing between adjacent pairs (e.g., Jones, Peryam & Thurstone, 1955) and yet they remain widely used, despite the simplicity of two anchors, and the assured linearity of the response/stimulus function.

The two labelled response positions should evoke familiar quantitative categories of a single qualitative category of feature. The most objective anchor, and the one that allows the most precise judgments, references the most familiar level of the category in the culture generally. If the quantity is in private experience, then the most extreme amount imaginable may be the safest higher anchor. Where absence of the feature is familiar, a level judged as zero can be used as the lower anchor. Such an anchor is needed when raters might believe that the feature is absent at a low level of the stimulus; the investigator can then avoid the floor effects liable to be produced by testing samples near the lower limit of recognition.

Rows of boxes with most familiar or preferred level as a mid-anchor, and unrecognisable or unacceptable as the lower anchor, have routinely performed linearly against discrimination-scaled distances (Booth *et al*., 1983; Booth, Earl & Mobini, 2003; Conner *et al*., 1986a, 1988a,b,c). A row of the eight integers from zero to seven for judgments of the current level of an adverse state, as verbalised by sufferers themselves, has given linear and normal data in many studies in different countries (e.g., for chronic fatigue in rheumatic disease, Bowman, 2008; Bowman, Booth, Platts *et al*., 2003, 2004; Bowman, Hamburger, Richards *et al*., 2009; Goodchild, Treharne, Booth *et al*., 2008; Segal, Thomas, Rogers *et al*., 2008; Seror, Ravaud, Mariette *et al*., 2011; Strombeck, Theander & Jacobsson, 2006).

When one of the two anchored response points is scored as zero (whether or not numerical responses are used), the observed ratings can be taken to have full psychological measurement properties (in ratios as well as intervals) until there is evidence to the contrary, such as consistent failure of norm-zeroed discrimination analysis.

Linearity of performance

The key to investigating personal cognition is to provide the opportunity to respond linearly to conjunctions of salient stimuli. Linearity of the response/stimulus function can be assumed if procedures have been implemented that keep stimulus levels within the range of constancy of Weber's fraction and avoid distortions in the response measures.

Furthermore, this working principle can be tested against plausible alternative hypotheses on the collected data. The first stage of testing among hypothesised causal processes can compare equal interval (untransformed) with equal ratio (logarithmic) stimulus levels for fit to levels of each response. That is, linear and semi-logarithmic functions can be tested against each other routinely. It should be noted that these tests are done on individuals' data from single sessions, not on grouped data, and that the choice of the two functions is theoretically based, unlike a polynomial for example (Nihm, 1976).

Normalcy of performance

Both least-squares regression and the calculation of Weber's fraction presuppose that the probabilities of responses are normally distributed, and indeed have the same dispersion at each stimulus level (Figure 2). As Thurstone (1927b) pointed out, this assumption can be checked empirically. In the first experiments using this approach, which minimised known biases on quantitative judgments, responses above and below the norm anchor had indistinguishable standard deviations (Conner & Booth, 1992).

When responses are near-normal, least squares regression is remarkably resilient in practice to the square distributions of stimulus levels that are desirable to minimise biases (see the section below on the design of a session). Indeed, just two levels of a stimulus can be used, without resort to logistic regression. The same assumptions about stimulus distributions are made in *n*-way factorial analysis of variance as a special case of multiple regression. Nonetheless, quantitative sources of input are to be preferred whenever available, because they provide greater precision and realism.

Weber's fraction from an individual's session

The unit of measurement in personal cognition

A response's differential acuity to a stimulus provides the generic unit of measurement of causal strength by norm-zeroed discrimination scaling. The individual participant's Weber fraction for each measured stimulus feature is determined for a response in each set of tests within an experimental session or period of observations. The calculation divides the slope of the line into the root mean square error of the least squares regression from stimulus values to response values (Torgerson, 1958).

Each test sample's distance from the norm on each response-stimulus function is calculated as a number of Weber fractions. These distances are arithmetically determinate from the data-pairs entered into the regression. The least squares fitting to the data is used as an estimator, not a statistical evaluation.

The half-discriminated disparity

Weber's fraction is often said to be based on an arbitrary choice of percent correct - for example, 75% rather than, say, 60% in tasks where 50% is random and 100% is always correct. That view is ill considered. The relevant fractional increase in level of the stimulus is halfway between complete success and complete failure at discriminating. The two stimulus levels that are half-discriminated have response probability distributions that superimpose the upper quartile of responses to the lower stimulus on the lower quartile from the higher stimulus (Figure 3). The (infinite) areas under the two curves are half overlapping (Booth & Freeman, 1993; Conner *et al*., 1988c).

Figure 3 about here

Each word in the term 'half-discriminated disparity' (hdd) is carefully chosen to replace the longstanding 'just-noticeable difference' (jnd). Discriminating is performance, whereas noticing is phenomenology. What counts as 'just' on the edge between noticeable and not noticeable is totally subjective and indeed arguably paradoxical: how could one judge if something is not noticeable? Furthermore, the data could only be about what is noticed in the test as run; what the participant is 'able' to notice is a further question. Weber's fraction is used in personal cognition to measure what has actually been discriminated during the individual's session, not what supposedly can be discriminated at best in any situation (let alone at every level of the stimulus).

The ‘difference’ in the term jnd is also phenomenological -- a difference in intensity between two sensations. The performance of discrimination between levels of the stimulus is on ratios of physical measurements of sensed material characteristics, or between differences (intervals) in level of symbolized cultural attributes (e.g., verbalized concepts), as shown above. The term ‘disparity’ spans ratios and differences.

Weber’s fraction, or the hdd (jnd) ratio, is dimensionless in the sense of that term in mathematical physics, because the stimulus units have cancelled out. Nonetheless, the discriminated levels of the stimulus are measured in a particular unit. Furthermore, the fraction or ratio is specific to the response and to the context that affords the norm. Hence the degree of discriminative acuity is relevant only for the individual and situation in which it has been estimated.

Point of equality to the norm

The calculation of Weber’s fraction also provides an estimate of the objective point of equality to the standard used in the quantitative judgments on the presented levels of the stimulus (Torgerson, 1958). Again, this equality is a parameter value of performance, not a matter of phenomenology: the traditional term, ‘point of subjective equality’ is a misnomer. The subjective interpretation of this matching level presupposes that the varied and constant stimuli evoke conscious states of intensities of sensation. Yet the task may not evoke any private experiences of that sort. Also, the standard used is personal to each participant, not necessarily the level of any constant stimulus provided by the experimenter. Yet this individuality is a public achievement, whether or not it is also privately experienced in some manner.

Hence the response-stimulus function for an individual’s session gives the amount of each varied stimulus that the participant assigned to the norm anchor category, if that was explicit on the layout for responding, or to whatever norm was implicit in the participant’s physical or symbolic responses during the session. This matching point is the stimulus level at the centre [(0,0) point] of the hyperbola that best fits the data. The calculation of the point of equality to the norm is not separate from that of the half discriminated disparity.

The stimulus level of the norm is sometimes used as a measure of sensitivity. Individuals with peak responses at lower levels are regarded as more sensitive to the stimulus. However this conception of sensitivity has a different mathematics from both differential sensitivity (Weber’s fraction) and detection sensitivity (*d*’), because each of the three is a distinct acquired skill. It would be surprising if extreme insensitivities of detection or discrimination did not go with high norm points (e.g. Booth, Sharpe & Conner, 2011b). Yet in principle the insensitivity might only produce a greater scatter of norms. The actual pattern depends on pathways of development through the options in the environment that have been left open by the genome at each stage of genetic expression and cultural inculcation. Conversely, extreme sensitivity is likely to lead to a low norm but the individual might cope with the cultural average in some other way, acquiring a more usual norm.

For example, great sensitivity to bitterness might induce a lifelong dislike of coffee or mature cheeses. Yet early lack of options could lead to a liking for coffee if weak or for cheese if mild. A third possibility is that regular coffee or cheese becomes greatly liked in early adulthood because of its exciting taste. Effective investigation of such developmental channelling depends on measuring discrimination and norm before and after each step in development in the individual (not in a cross-sectional design).

Other measures of differential sensitivity or causal strength

The calculation of Weber's fraction combines the slope of the regression line with its error, i.e. the variance in the deviates from the line (Figure 3). Yet measures of the sensitivity of a response or the strength of influence of a stimulus have often been limited to either slopes or variances, even in psychology, let alone in other basic or applied sciences.

Slope

To measure sensitivity, natural scientists and engineers have usually deployed slopes, such as calibration lines, dose-response functions, and percent of perfect functioning. This reflects their confidence that their experiments are good simulations of the causation in nature or in the physical machinery.

In contrast, experimental psychologists betray doubts that they can understand the mechanisms involved. They often opt only to compare a single experimental condition with a control condition, or to test between mere binary opposites (Newell, 1973; Shepard, 2004). As inevitable for systems of causation, such lines of experiment run into complexities. Then contexts have to be better specified. Factorial designs might be tried. This gives a chance for a task-specific slope to emerge. The field of visual search provides a good example (Wolfe 1994).

Indeed, experimental psychology is more qualitative than often recognized. Analysis of variance (unless factorial) reduces all independent variables to categories. Typically two distinct categories of condition are used as experimental and control; this precludes measurement of the independent variable. The favourite response -- reaction time (RT) -- is merely a categorical Yes/No. Ignoring RT errors (or minimising them) throws away the opportunity to gather evidence on structure in the processing from stimulus to response. Reaction times are reassuringly numerical and appear to be free from supposed vagaries of words. That however is an illusion, fostered by the refusal to listen to what subjects say. Key presses communicate "Yes" or "No" by a conceptual criterion requested in the instructions. The analysis of errors can be illuminating but is greatly bettered by diagnoses from ratings of an overall degree of match or of specific concepts. That is sufficient to identify a response construct that can be related to any hypothesised causal factor in the context.

Variance around the line

To assess causal power, social scientists on the other hand have favoured the regression coefficient (r), i.e. the complement of error variance ($1 - r^2$). However, the collecting of data is often not designed to test among causal hypotheses appropriate to the context. It can be prohibitively costly to collect population-representative data, whether in the aggregate or individual by individual. The mining of archival or survey data is necessary. Therefore model-testing modes of multivariate analysis are especially important (Pearl, 2000). Yet these analyses specify only sizes of effect such as the partial regression coefficient. Parameter values are often not considered at all. Hence, even if causation is established, the model is non-predictive because initial conditions are unknown and so their transformations are indeterminate.

Discrimination requires both slope and variance

Neither slope nor (lack of) error is satisfactory on its own. The value of the slope carries no estimate of the reliability of that value (unless confidence limits are also stated). The regression coefficient, or its square (the variance accounted for), provides only the statistical effect size, with no measure in observation units of the actual size of the effect of the influence on the consequence.

A measure that relates solely to variance, without reference to slope, is sometimes called a jnd -- for example, in measuring the social response to the physics of a picture (ITU-R, 2012). Other variants include judgments' root mean square error itself, the proportion of experts who judge a difference in the wrong direction, or a function with finite tails, in order to cope with big disparities (Keelan & Urabe, 2004). These are objective measures of variation in the judgments on the material stimulus affordances of pixel arrays, e.g. luma and chroma (Lubin, 1997; Yang, Chen, Tian & Wu, 2012). Nevertheless, individuals' context-specific Weber fractions would improve the speed and accuracy of measurements (for color vision deficiency, see Flatia & Gutwin, 2011). Psychology could have given a lead a century before the pixel was invented.

In short, the slope component of Weber's fraction cannot be replaced. The data points on the slope capture the content of information, rather than just its amount. The slope is in terms of measurement values of the source and sink, information which is lost in the slope's error or the explained variance. The norm reveals the structure used to extract content from the stimulus in terms of the response. The peaked response-stimulus function by itself can show how close the context investigated is to the most familiar situation, while error in the data remains a mystery.

Determinate processing under environmental constraints

Uncertainty in a feature's value

Norm-zeroed discrimination scaling provides determinate axioms and algorithms. However some decisions are made in situations of explicit uncertainty. Heuristics then come into play, as proposed by prospect theory (Kahneman & Tversky, 1974). These decision-making principles deal with levels of stimulus and response affordances that are unknown to a major extent. The heuristics are far from sufficient to account for the dynamic structure of mental states, either in general or for concrete examples. The exact calculations of personal cognition are therefore needed as a base, with heuristics for handling uncertainty to be activated when needed.

Prospect heuristics provide accounts of dependence of decisions on sequence or time-lagged effects of context, although there are difficulties with some specifics. Principles from quantum physics have been claimed to help (Pothos & Busemeyer, 2013). However, it seems unlikely in principle that non-classical indeterminacy will do better because of the problems arising from lack of specific content in the heuristics. In personal cognition, sequence effects can be related determinately to changes in salience of features (see below), similarly to integrated weightings (Birnbaum & Gutierrez, 2007).

Contextual limits on processing each feature

Number of features being processed. More fundamental than external uncertainties are internal limits on the number of features that can be implicitly measured in one test sample. How many of the monitored features an individual actually used in a session is estimated from their strength of influence on the response of interest, i.e. the features' saliences measured as their differential acuities over the session. Both the number of features and the number of levels distinguished are limited by the capacity of the interaction between perception and retrieval of the norm from memory (Baddeley, 1994). There may be corollaries for the time taken to decide.

Sequence of processing. On the present theory, the determinants of an intention or involuntary reaction start with implicit comparisons of features of the situation with features in a norm acquired on previous occasions. The norm categorises affordances of the social and material environment and contrasts the environmental levels with the norm's levels. This basic process is independent the sequence of processing salient features or the durations of attention to each feature. The situation (including compliance with an experiment) may impose a sequence of explicit processing of selected features (as in sensory profiling) and/or some time constraints on completion of the action (as in reaction times). As with uncertainties, sequencing and speeding superimpose heuristics on the underlying norm-zeroed discrimination scaling.

Strength of influence of a feature

Relative power of an affordance

The salience of a feature, and the current attention paid to it, is the relative strength of influence that the feature has on the response to be explained. This active causal power of information in an input or output affordance is measured as the proportion of the variance in the response explained by the feature.

As with any analysis within an individual, this measure of salience applies only to those test samples during the session that were treated in the same way. In the theory of norm-zeroed discrimination, this means that the samples were compared with the same norm. The closer that one of the hypotheses based on multiple discriminations comes to accounting for all the variance in the response throughout the session, the more consistent must have been the processing across the tested variants of the situation.

Nevertheless, the estimated salience of a feature is an average of degrees of salience that may have varied among the tested samples. Attention may shift to or from a feature between samples. An intentional shift in attention may arise from a change in thinking. An effortless shift may come from an extraneous event. An important case is a change in salience induced by a previous sample. Norm-zeroed discrimination theory provides a fully specified version of this type of explanation of effects of sequence on decision making.

Intransitivity of choices

Much attention in decision theory has been paid to inconsistency of choices between the different pairs of three situations. The choices considered have generally been gambles (Tversky, 1969, but see Birnbaum & Gutierrez, 2007). Far less work has been done on decisions among currently present situations or items. Missing attributes have been invoked but this is unlikely in choices among real situations or for competing items within a situation. Incomplete scanning of attributes seems more likely, and has been proposed to occur at random (Kriesler & Nitzan, 2008)

For decisions among probabilistic prospects, a powerful approach to explaining intransitivity and other paradoxes of choice invokes the setting of a reference value for each feature (Kahneman & Tversky, 1974). The learnt norm is a version of such an approach that is fully constrained by the data. Instead of comparison with reference prospects, the present approach compares the relative closeness of the presented levels of different common features to their ideal values. Varying salience could generate a similar explanation of intransitivity.

The simplest example is a sequence of observations that A > B, B > C and C > A, where > means preferred to, in the sense of chosen over. These data can be explained if A and B have a (salient) common feature on which the first choice was made, whereas B shares a different feature with C on which the second choice was made. The paradoxical third choice could arise if the levels of the feature in common between A and B were both further from its norm point than the B-C commonality was from its norm. Then, overall, C could be closer to the norm than A.

A sequence-dependent intransitivity (e.g., Anderson & Matessa, 1997; Altmann, 2000; Luchins, 1957) could be generated by salience alone, even when the three items had all features in common. In the above situation, for example, if A and B both had features relatively far from norm, that extreme might draw greater attention subsequently to features with levels close to the norm, determining the choice between B and C. The increased salience of features close to the norm could reverse the status of A relative to C (and to B, if A *versus* B were re-tested).

Identification of a causal process

Correlation proves causation

Great confusion has arisen from statements that correlation does not show causation. On the contrary, the repeated observation of a reliable correlation of quantities (or association of categories) is proof that causation exists. What is unknown from such evidence by itself is the direction(s) of that causation. On the basis of the correlation alone, either or both of the two variables could be a cause or an effect. If neither variable can be shown to be an influence on the other, a third variable is causing them each to co-vary with the other.

Failure to identify the direction of causation is not a flaw of the correlation statistic either. Analysis of variance does not in itself establish direction of causation, any more than regression from one variable to another turns the predictor into an influence on the criterion. ANOVA is merely (multiple) regression with categories or group-wide fixed levels serving as predictors. What usually turns the predictor(s) in an ANOVA into independent variables is experimental manipulation of the categories to be statistically independent of each other, or to be uncorrelated ways in factorial ANOVA. The question is how those orthogonal relationships in the data are achieved. The answer rests in the relationship between data and theory.

The philosopher David Hume (1748/1902) argued that constant concomitance gives an illusion of causation. That can be psychologically true: if two events are seen in close proximity in time and space, there can be a powerful impression that the first event caused the second event (Michotte, 1963), whereas in fact the experimenter caused both events. However, this paper is not about an individual's perception of causality. The issue here is what evidence society has for the existence of a causal process within an individual's mind.

The implication often taken -- that the inference of causation from correlation is fallacious -- is itself built on the fallacy that knowledge can be built from bare observations (or worse, from private impressions). Rather, empirical knowledge is built by testing relevant observations for consistency with a hypothesis derived from a theory that explains existing observations within its scope and implies observations that have yet to be made (Lakatos & Musgrave, 1970; Popper, 1963). If a theory predicts that event V causes event W, there is strong evidence against that hypothesis if each event recurs on its own but V and W have yet to be observed to occur together.

Evidence for a particular causal process

Delay between cause and effect

In other words, the issue of causation does not arise unless the two theoretically relevant events occur together more often than coincidences predicted from their separate probabilities. The logically very first step is therefore to gather evidence whether or not the two events occur together in the context required by a substantive hypothesis from a well developed empirical theory. Then, however, there remains a problem of testing if one of the events is causal and the other an effect of it. A solution requires further reference to the theory.

Usually in psychology, a small delay is expected between the start of a causative event and the start of its effect(s). It takes a finite time to transform incoming information into outgoing information, even without any intermediate processes. Hence the evidence for concurrence of the event needs to be sensitive to time-lags between starts of events, within the theoretical duration of action of such a cause on such effect. The putative cause starting before the effect is consistent with the hypothesis. Concomitance with a time lag only the other way round is evidence against the hypothesis and consistent with causation in the reverse direction. Time lags both ways are consistent with causal processes in each direction.

Experiments that apply a stimulus and record an effect may not need to measure the latency between starts. When timing is measured, as in reaction time experiments, the delay is evident and the inference of causal direction is trivial. The problems come with attempting to use response latencies alone to identify the nature of the transformation from stimulus to response (e.g., Mordkoff & Miller, 1993). Error rates under different conditions provide some evidence, but such data are usually unsystematic.

These difficulties in interpreting reaction times arise because adequate data on the structure of the transformation are not available, or not even sought. Many simple-looking experimental designs, such as the controlled clinical trial, have the same defect. The observations do not focus on what is happening from the start to the end of the period during which the experiment's intervention is actively causing effects. Typically the hypothesized outcome is measured much later. Continued direct influence by the intervention may not be monitored either. Tracking potentially mediating processes is crucial to understanding how the intervention worked, especially when psychological processes are involved. For example, antidepressants of different sorts have been found to act via side-effects that patients are informed about or are mimicked by placebos that act on the autonomic nervous system (Greenberg, Bornstein, Zborowski *et al.*, 1994; Mora, Nestoriuc & Rief, 2011; Thompson, 1982). In short, the vaunted randomised controlled trial makes so many naive assumptions that it amounts to nothing more than a weak observational design using cohorts.

These problems are worse still in multivariate research, even with time-lagged analysis. Structural models seldom specify states within the minds tested. Psychological variables are typically limited to individuals' positions on broad and stable consensus variables. Mediating processes need to be tracked in each individual. Attempts to generalize should be left until the causal processes within a relevant set of minds have been characterised.

An individual's single session

Causal interpretation of each successive pair of data

The principle of discrimination between a situation and a norm generates a determinate interpretative procedure, with or without experimental manipulation of the occurrence of the hypothesized cause. Observations can be evaluated one by one as they come in. An initial misinterpretation can be corrected by the next observation or two.

If there is not already a causal hypothesis for the two categories of event in the context, the first observation has to become support for the hypothesis, in order to treat each subsequent datum seriously. For the purposes of illustration, the initially observed pair of data will be taken to be positive concomitance, i.e. co-occurrence of the two events in the top right cell (1,1) of the 2 x 2 association table of Figure 4. The logic used below applies equally to an initial observation (data-point 1) in any of the other three quadrants of Figure 4. The events could be re-coded into the cell (1,1), even if one or each of them is in fact the non-occurrence of that particular event.

Figure 4 about here

The logical possibilities for the second and indeed each subsequent observation are a pair of events in any one of the four quadrants of each panel in the first row of Figure 4. Recurrence of an observation in the upper right quadrant supports the hypothesis (Figure 4, second row). An observation in the lower left quadrant is also compatible with the hypothesis. However, an observation in either of the other two quadrants is contrary to the hypothesis.

Each of the two observations consistent with the hypothesis has the possibility of a third hypothesis-consistent observation of 0.5, reducing the probability that the hypothesis is false to 0.25 (Figure 4, third row). The same logic applies to each successive observation. Hence six observations without the pair of events appearing in either the upper left or lower right quadrants has an *a priori* probability of 0.03125 (0.5^6), better than the conventional threshold of reliability, $p < 0.05$. That is, a mere six observations of only upper right or lower left pairs have a probability of about 3%. Two more such data-pairs reach better than $p < 0.01$. A pilot study with five observations can approach conventional statistical significance, at $p = 0.0625$, providing some justification for full-scale investigation.

It may be possible to select conditions, or to manipulate the situation, so that one of the relevant events always occurs, i.e. limit the observations to the upper or right-hand two quadrants in Figure 4. The probabilities of the other event co-occurring remain the same.

Quantitative concomitance

Paradoxical edge of absence

Such tests for constant concomitance are logically sound but the categories of present and absent are over-restrictive. Indeed the notion of a borderline between presence and absence is a source of fundamental confusion about perception. In both fundamental and applied sciences, absolute thresholds are often treated as the be-all and end-all of sensory measurement. The practical issues alone make the persistence in this approach very strange. The usual procedures for determining a supposed threshold for apparent presence of a stimulus are laborious. The numbers obtained are highly variable. The logical flaw in recognition of absence is fatal. Yet these values for the putative presence-absence borderline are used to measure the causal strengths of types of stimulus at levels far above detection. For example, various forms of the ‘odour number’ remain popular in research on flavours, fragrances and taints (ASTM, 2012): this is in effect the reciprocal of a value for the ‘absolute threshold’ for a volatile compound. Yet, when tested, measures of detection and discrimination correlate poorly (Mojet, Christ-Hazelhof & Heidema, 2005). Another example is the common practice of using measures of sensitivity to the presence of a stimulus to estimate the strengths of effect of readily detected levels on preferences (e.g., Harwood, Ziegler & Hayes, 2012; Lucas, Riddell, Liem *et al*., 2011), despite the long known lack of correlation (Pangborn & Pecore, 1982). How much influence a sensed material characteristic has on choice is an issue of discrimination from norm, regardless of detection limit.

In contrast, the usual issue is not whether a feature is present or absent but how much of it is present, relative to the level that is expected. Detection can be important but for acting in emergencies, not for dealing with ordinary situations.

Judging quantities

The above consideration of categorical evidence for causation can be converted to a quantitative treatment by replacing presence and absence by higher (H) or lower (L) ranges of levels of graded features (Table 1). The dummy coding of cells can still be 1 or 0 but 1 means high (not merely present), and 0 means low(er). The low range does not exclude absence but should not be so low as to be beyond the range of Weber fraction constancy or where the slope of the psychophysical function declines below semi-logarithmic (Laming, 1986).

Table 1 and Figure 5 about here

Furthermore, a categorical or ordinal feature can be rescaled as a quantity, whether of an effect such as a response by the individual or of an influence such as a stimulus feature. The higher and lower levels can each sample their own range of values, for example producing an evenly spaced set of amounts of the putative influence. This design provides data amenable to linear regression, even with only three observations (Table 1). The slope of the regression from 100% or 0% of the influence or any set intermediate values provides an estimator of the strength of the causation that produces the observed regression coefficient.

The testing can be more sensitive with a different quantitative stimulus level in each sample. A reliable pattern may be seen even with points in the crossed quadrants. From linear regression through six cases, an r-value of 0.71 or more has the conventional $p < 0.05$. Even with only four cases, r = 0.82 reaches $p < 0.05$.

Finally, if the data are monotonic from below the norm to above, they need to be folded in order to calculate the interactions between different output/input functions. In consequence, designs that test only two stimulus levels need to place them both on the same side of the norm; otherwise, the folding point is indeterminate. That is, the data must resolve a norm value that lay between the two levels of the stimulus from a norm that was far beyond one of the levels.

Selected observations or experimental manipulation?

The present approach works for either experimental or observational designs, and a range of combinations and extensions such as quasi-experimental and self-observational studies. Indeed, there is no fundamental divide between experimental and non-experimental tests of hypotheses. Each extreme ultimately needs the same intensive investigation for hidden mediators and moderators. The critical requirement is that the observations are confined to a context in which the theory specifies that the causal process could be occurring. Mining arbitrarily collected sets of data, looking for inspiration of some hypothesis, turns this logic on its head and is liable to be seriously misleading through neglect of crucial contextual factors.

When the data have not been generated within an ecologically valid experiment, data pairs have to be selected to fit the relevant experimental design. The usual manipulation of stimuli in psychological experiments is in fact the selection among affordances, if the hypothesized independent variable is to have any effect on the observed response. A vital issue is what such manipulation has done to the context, but that is seldom checked. Norm-zeroed discrimination analysis screens for such artifacts by measuring contextual defects.

A context has to been found or created where the each of the two events can occur or not occur. Then no observation of either occurrence is omitted from analysis of the data. For example, if a medical trial is to be valid, once the criteria for inclusion and exclusion of patients have been applied, all patients are entered randomly into the experimental or control conditions and the measurements of outcomes (‘intention to treat’ design).

Ill considered manipulation or selection of samples on a variable can create artificiality that distorts the situation and stresses the system. It is better to monitor known likely confounding variables and to re-test the same hypothesis in a situation having other sorts of potential confounders. At the very least, serious departures from norm should be identified and rectified in subsequent experiments.

A norm and its environmental affordances, both stimuli and responses, are always affected to some extent by any investigation. At the very least, the observed values have to have been recorded. Many observational designs greatly constrain the response affordances by asking questions in a particular way. This can range from an interview that is structured in accord with the investigator's preconceptions, to ratings that impose verbal or pictorial anchor categories and positional or numeric formats in accord with a research tradition rather than the requirements of measuring specified causation.

These considerations cast in question the claim that the direction of causation inferred from time-lagged observations can be validated by experiment (Pearl, 2000). The experimenter's intervention alters the situation. These threats to valid inference can be minimized by use of observations to study what theory based on experiment implies are unmediated effects of the cause on the effect. Those observations need to be confined to the period when the mechanism is active, i.e. the causal event is occurring. Also there should be time lags between observations that match the duration over which the hypothesized mechanism becomes active.

Minimum biases

To sustain the opportunity to respond linearly, major distortions of performance need to be avoided. This can be done by designing response formats and sets of test stimuli so that successive samples in an individual's session can be selected to avoid known sources of nonlinearity and to keep each feature of the samples within the range of a constant Weber fraction. That discipline also helps to keep the session's simulated situation the same from the individual participant's point of view, i.e. close to her or his own acquired norms for percepts and intents.

The most important threat to linearity is an end effect. Typically this results from a ceiling or floor created by a limit on the options for responding. Presentation of a stimulus level outside that limit forces performance off a straight line relationship between response and stimulus.

Test stimuli having strengths at the higher end of a range tend to lower the average value of the responses (Parducci, 1965). Hence, in the presence of that range bias, a stronger stimulus is needed to match the assessor's personal standard, such as the most preferred or familiar level.

A wide variety of distortions from linearity can be characterized in terms of mismatches between response format levels and the distribution of stimulus levels (Poulton, 1979, 1989). Besides range and frequency biases, there is also a centering bias (Poulton, 1989). This can be minimized by presenting the first test variant of the situation with each of its features at close to the familiar level. If any feature in that first variant is assessed as being at the personal norm, it can be presented in the second variant at a level readily discriminated from norm. Interpretation of the data obtained so far can be refined as each new datum comes in, so that range bias and end effects, and finally frequency bias, can all be minimized for each participant during the first session of testing a situation (Conner *et al*., 1988c).

A quite different flaw in design is miscommunication of the concept on which the quantitative judgment is made. One of the commonest distortions imposed on participants is the provision of multiple or even mixed categories. The categorical terms on the anchors must be identical, and also the same as in any question asked alongside the layout for responding. The two anchors required to specify a straight line must differ only in their terms that imply a difference in quantity.

This error is inherent in bipolar format, with scores from positive to negative. The supposed 'opposite' to the positively scored concept is inevitably a different concept, having other determinants. The absence of a stimulus is merely noise; it should not be scored as a negative feature. As levels of the stimulus are lowered, an adverse attitude may develop at some point. If so, perceived absence of the stimulus may be strongly aversive. That can result in a response which differs from judging levels of the stimulus nearer the norm and needs to be separately measured (e.g., Booth, Higgs *et al*., 2010, for pleasure and displeasure at different strengths of a stimulus).

Efficiency of method

The power of such design has been shown by the small number of data needed to obtain useful estimates of the norm point and Weber's fraction for a response/stimulus function from a person in a session (e.g., Booth *et al*., 1983; Booth, Higgs *et al*., 2010; Conner & Booth, 1992; Conner, Haddon & Booth, 1986a; Conner *et al*., 1988c). If investigators start with a realistic hypothesis about a feature, then samples can be selected from the start to have at least two levels of that feature at minimum correlation with any other known feature. The response/stimulus regression formula works on as few as three samples that include two levels, although of course more data provide greater precision.

That economy of effort contrasts sharply with the large amounts of data collected traditionally, and still today, in both academic psychophysics and applied sensory analysis. The bivariate regressions also contrast with complex statistical maneuvers unconnected with tests for causal mechanisms involved. Norm-zeroed discrimination bypasses the laborious testing methods built on Thurstone's (1927a) principle of comparison and the packages of generic statistical models for unfocused collections of data.

Hence, the thrust of a theory of individuals in situations has been missed if large bodies of data are expected in support. Sufficient data can be obtained from an individual in a session to characterize what is going on in that mind at that time – for example, 80-99% of the variance in a response accounted for by a single discrimination scaled model. Such a finding also shows that the participant's quantitative skills can be trusted.

Interactions among response-stimulus functions

The fitting of each participant's raw response data to stimulus data scaled in Weber fractions from the norm for each session enables the resulting response-stimulus functions to combined in theoretically relevant ways. Comparisons among these combinations provide tests for specific and detailed hypotheses about the mechanisms by which a mind operates in a situation . The second paper in this series takes up this step in analysis.

Part Two

How a mind works.
II. A fundamental theory of the individual's action, perception, emotion and thought

Abstract
The six simplest sorts of process are specified. The distinctions among them correspond to classic categories of mental mechanism.

Types of norm-zeroed discriminative process

Ambiguity of a single response-stimulus function

The psychophysical function from a single response and a single stimulus cannot distinguish among the mental processes that could have mediated that discriminative performance. Without further data, there is no warrant for the common assumption that a sensation or conscious percept is involved, as encapsulated in the subjectivist term 'magnitude estimation' (Stevens, 1957). The participant may be reacting solely to the level of sensory stimulation, maybe even unconsciously (Figure 6). Such a mental performance is often assumed to be merely neural activity. Again though, without data that exclude other possibilities, such mediation by any sort of purely sensory process cannot be assumed. A third hypothetically feasible mediator is a stimulus-specific (analytical) verbal categorization process (Figure 6). For example, the assessor may be conceptualizing entities that feature different levels of the stimulus and mapping those entities into the intensity ratings.

Figure 6 about here

Such cognitive ambiguities in standard psychophysical data led to a general theory of types of basic mental process involved in any intelligent engagement with the environment (Booth & Conner, 1991; Booth & Freeman, 1993). The theory depends on combining response-stimulus functions in ways that dig deeper and deeper into the mind of an individual dealing with a situation.

Hierarchy of interactions among response/stimulus transforms

As illustrated above for a single psychophysical function, a variety of covert mental processes could generate the observed transformations of levels of a stimulus into levels of a response. Evidence of interactions between two or more observed response-stimulus functions might help to disambiguate the interpretation. In particular, the evidence could turn out to be that processing of the response and/or the stimulus in one function affects the processing behind another function.

There has been vigorous argument over the above three possibilities for many decades. Yet very little extra evidence is needed in order to distinguish among them. The minimum data are two levels of the stimulus and two categories of quantitative response, one of which is more inclusive or general than the other. Norm-zeroed discrimination analysis of such data from an individual's session can test for the strength of influence on the broader response from any of the above three types of mental process.

The most overt mental process is measured as the influence of an observed stimulus on an observed response, whether the response is highly specific to the stimulus or potentially integrates information from two or more stimuli. Also evident directly from the observed data, the analytical response category may be used to judge how far the wider situation is from what is usually conceived; in this case, there is no direct reference to stimulus levels. A third possibility is an inferred process, which therefore has been called 'indirect' (Booth & Freeman, 1993). This more complex interaction is the influence on the integrative concept of the causal relation between the stimulus and the narrower concept. A further step in the hierarchy is for this covert response-stimulus function to affect the response-generating process or the stimulus-receiving process. These and other identifiable types of mental process are characterized in the following subsections.

Each of these theoretical possibilities is considered in turn as a model for the mental causation behind the response to be explained. The strength of influence by each hypothetical process on that response can be calculated from observations of an individual in an unchanging situation over a period of time that is brief enough for consistent performance.

Each cognitive model is given an acronym using an S to refer to data on a particular stimulus and an R to denote the data from one of the responses. Any causal steps within the influencing process are written from first to last, e.g. S_2R_2 refers to the process of R_2 being influenced by S_2. The regression $S_2R_2 \rightarrow R_m$ models the hypothesis that the psychophysical function, R_2/S_2, influences the response being modeled (R_m). If R_2 is a culturally accepted term for the concept of the affordance S_2, then R_2/S_2 is an 'analytical' psychophysical function.

Six types of influence on a modeled response are now reviewed in turn, from the more peripheral to the more central (Petty & Cacioppo, 1986) or shallower to deeper levels of processing (Craik & Lockhart, 1972).

Conceptual influence ($R \rightarrow R_m$)

Effect of another response

The first type of mental interaction to be considered is a response process that may be influencing the response process to be explained (Figure 7a). This is a response (R) model, calculated as the regression $R_k \rightarrow R_m$. Such influence cannot come from the overt responding itself when that response occurs later than the affected response. Rather the influence can be exerted by the mental processing that determines the overt response. Whenever that is the case, this influence of the response process on the other response is covert, albeit minimally so.

Figure 7 about here

The first test for this type of mental process was on the effect of the conceptualization of a specific feature of an object (R_n) on an overall response to the object (R_m), namely the intensity of a taste on the degree of preference for the test sample (Booth & Freeman, 1993). The norm point that was constructed from memory and the Weber fraction that was achieved in the test session are estimated by least-squares hyperbolic regression from the analytical response to the integrative response.

The calculation does not involve any data on the stimuli presented. This model is based solely on patterns of responses. When two or more responses are available in addition to R_m, those data need reducing to orthogonal multivariates, e.g. by principal components analysis. Nevertheless each response or latent variable is treated as the input to a causal process. Hence the analysis is psychophysical in principle rather than purely the psychometrics of patterns in responses (Booth, 1995). Conceptualization operates independently of stimulation in other uses of memory, such as priming of person recognition (Boehm & Sommer, 2012/in press).

When objects having many features are used as test samples, sets of the stimulus-specific concepts are commonly used in an attempt to pick out different features. Wider judgments of the objects may not be elicited. Nevertheless the participant may make broader evaluative judgments implicitly, or even explicitly but unrecorded. These more integrative responses may include overall judgments, whether categorical such as naming or quantitative such as familiarity or attractiveness.

Measures of response concepts as covert stimuli

Quantitative responses can be treated as a covert stimulus in a variety of ways. The most fundamental approach is to calculate the mental causation of each case of an observed response (R_k) from the session's data and then to test that norm-zeroed discrimination-scaled estimate as a stimulus element for the integrative response to be explained (R_m).

A less laborious but approximate approach is to estimate the causation of each response from the session's varied stimuli only and uses those S models as stimuli to the response to be explained. This procedure is also used to estimate the relative contribution of each stimulus to the causation of a response. For example, a sensory term such as bright, loud, heavy, bitter or smelling-like-a-rose is shown to be analytic if it is dominated in discrimination scaling by the hypothesized sensed characteristic, e.g. luminosity rather than hue or saturation, power of the sound rather than its frequency, hefted weight rather than applied pressure, caffeine or quinine and not citric or malic acids, and the volatiles from roses rather than chocolate or manure. On the other hand, terms like savory taste, strawberry aroma, or the flavor of apple or orange, have been shown to be integrative -- in those cases, within or across modalities of the chemical senses (e.g., Auvray & Spence, 2008; Booth, Kendal-Reed & Freeman, 2010; Booth, Freeman, Konle *et al.*, 2011).

The simplest approach, albeit a theoretically crude option, is to estimate the covert stimulus from the raw ratings during the session. If not in the format of differences from norm, the ratings should be converted to scores with one of the two linearly operative anchors as zero. This zero-scored anchor should rather be designed to denote the most familiar form of the test sample within the material and social situation simulated by the experimental session. Using this procedure, the name for the taste of an ingredient was shown to have a strong influence on the rated liking or relative acceptance of samples varying in that ingredient (Figure 1).

Quantity of a quality

Quantitative judgments are generally considered to be limited to stimuli that have intensive percepts. That view does not allow for complexity of causal structure behind the concept under which the judgments are made. In fact, even a feature that can only be present or absent in its perceptually pure form has quantities of 1 and 0 (or 100% and 0%). The issue is how such a feature can be perceived as partially present, in a position between 1 and 0. A resolution comes from the fact that each feature of any entity has a context of other features of that entity. Information about the feature has to be extracted from a combination of levels of other features.

In other words, the norm combines features in quality as well as quantity. The levels of two features in a test sample can vary both in combined strength and in degree of off-balance (Booth & Freeman, 1973; Booth, Kendal-Reed *et al*., 2010). Theoretically, strength forms a straight line with levels of the two stimuli that are at the ratio in the norm. Off-balance is orthogonal to that strength line. When other features are at levels away from their norm, an analytical rating of the intensity of a categorical quality may be placed at an intermediate position. In that case, the influences on the rating will include the other stimuli. In other words, the analytical response-stimulus function will no longer be a single line. There will be at least one other line emerging from the integrated context.

Descriptive influence (SR → R_m)

Theory

The hypothesis that the integrative response is influenced by the analytical concept (an R model) implies an appreciation of such a variation in the situation but with no attention to the stimulus to which the concept refers in the culture. The more usual interpretation of an analytical psychophysical function is that it measures conscious judgments of the strength of the stimulus. Indeed, the analytical terms are commonly called descriptors.

Hence an alternative hypothesis about an influence of a response concept on the integrative response is that the effect of the stimulus on the response in the analytical function (SR) affects the integrative response to be explained (R_m) (Figure 7b). This SR model was initially called ‘indirect,’ to contrast it with ‘direct’ influence from information from the stimulus alone or in the response by itself (Booth & Freeman, 1993; Freeman & Booth, 2010). Several other indirect processes have been hypothesized since and so this one has been distinguished as causation specific to the performance of describing. Applying a socially afforded concept to a material or social affordance may be considered to be a minimum specification of the logic of description.

Calculation

The potentially analytic response-stimulus function is rescaled in number of Weber fractions below or above the norm (cp. Figure 1). That is to say, the level of the stimulus in each sample tested in the individual’s session is assigned a directional distance from norm in units of the discrimination achieved by that quantitative response. This response’s norm-zeroed discrimination scale of stimulus levels then serves as the predictor variable in linear regression to the criterion of the more integrative response.

Meaningful influence (SRR → R_m)

Minimum theory of meaning

Evidence for the above conceptual (R) and descriptive (SR) influences on a response concept, as well as for stimulatory (S) influences (considered again later below), comes immediately from observed quantities. Hence these three types of process might be regarded as manifest in the data, or at least as sorts of relatively superficial thinking (Petty & Cacioppo, 1986). A more elaborated or deeper sort of processing would be an influence on the response to be explained (R_m) from the effect of one response-stimulus relationship (SR) on a response (R), i.e. an SRR model (Figure 7c). In other words, an overall response can be controlled by a description of that response's concept or of the concept behind another output. In short, the described concept gives meaning to the response it explains.

Motivation or emotion?

The content of the conceptualization of the description in an SRR process is specified by observed data for those R and S terms. That meaning can be 'cold' or 'hot', depending on the nature of the described concept (the second R in SRR).

If that concept relates to action, the SRR model is an account of the intentionality within the response it explains, such as opting between considered alternatives or expressing an attitude to a class of actions. The reasoning in the intention is modeled by the RR component (see next subsection). The S in the intentional control of R_m is the goal of the motive or, in B.F. Skinner's terminology, the reinforcer of that operant.

On the other hand, if the described concept is of reactive output, such as a term for a state of mood or an affective process, then that SSR model has the character of emotional content for the response accounted for. In I.P. Pavlov's terms, the S element is the unconditioned stimulus that reinforces the conditioned response that is to be made to the to-be-conditioned stimulus.

For example, the movement of an arm towards another person reaching the top of a stairway might be described as *reaching out*. If the reach is conceptualized as an attempt to *help*, that is intentional meaning. If, instead, the gesture is viewed as a *welcome*, it has emotional meaning. The meaning of the movement could be two-dimensional, both helpful and welcoming. Discrimination analysis of data collected on various extents of the reach could diagnose which of these mental processes was occurring, in a third party or indeed in either participant in an actual incident of that sort.

Calculation of the effect of a meaning

The norm-zeroed discrimination distances from the response-stimulus function of an SR model are used as stimulus values in a further regression to a response. The discrimination distances from the resulting SRR function are used to predict the responses to be explained by least squares linear regression. The variance explained can then be compared among models such as an SRR with another stimulus and/or response in the descriptive term, SR, R and S models, and other models described below.

Whatever the specifics of the two R elements and the S element of a meaningful influence, a better fit of this SRR model of R_m than of the SR or S models disambiguates the generation of the explained response from either description or stimulation. The same applies to its RR component, to which we now turn.

Reasoning influence (RR → R_m)

'Deduction' of one concept from another

The output being explained can be dominated by the effect an output's concept on another output's concept (Figure 7d; an RR model). One conceptual process causing another conceptual process is a minimum case of reasoning or, more specifically, of deducing the second concept from the first. This reasoning is not necessarily deliberative or effortful. The deduction may be involuntary or effortless. Indeed, the effect need have no rational basis. The process could be free association of ideas. The two concepts have the strongest connectivity in the semantic network which is currently active enough for their nodes to exceed threshold (e.g., Collins & Loftus, 1975).

At any given moment, the sensitivity of an intention to its reasoning may be poorer than an emotion's sensitivity to that deductive relation between its concepts. This conflict between two processes of meaning (SSR, above) is a minimum model of temptation.

Reasoned action

A reasoning process may explain a decision completely, i.e., RR accounts for all the variance in R_m. When both the concepts in RR are self-generated, this is a minimum model of free will (Baer, Kaufman & Baumeister, 2008; Mele, 2006, 2009). The act is causally determinate but by the agent's own reasons, not by compliance with anyone else. Also the determining causation is in the agent's own mind, not mechanisms in the brain or in society. Furthermore, where the concepts have ethical content, the decision is morally responsible, whether or not the agent or others consider that it was also correct within a substantive ethic.

The classical fork between freedom and determinism is incoherent for the same reason. Since there are no causal or logical connections between reasoned choice and physical movement, there has never been a genuine conflict. Neural or cultural determinacy is beside the point. The issue is how action from one's own reasons is possible by a psychological determinate system. The present theory gives an account of such possibilities within the mind, regardless of physical or social states. Philosophers, neuroscientists and humanities scholars have to engage with psychological science in order to address the conceptual issues effectively. Then the traditional mistakes become evident (Mele, 2006; Travis, 2012).

Third factors

Correlations among responses are the standard way of screening for influences over both events that are hypothesized to be causally related. This strategy assumes that the measure of an effect serves also as a measure of the cause. Hence RR models screen for confounders of hypothesized mediators.

The RR mechanism therefore puts psychology outside the range of problems with time-lagged multiple-regression analyses of causal networks (Granger, 1969) and more recent structural modeling (Pearl, 2005). In particular, a mediator of one causal pathway can confound the input to another path. The interactions among influences on behavior actually go on within each person's mind, not along paths between measurement nodes in grouped raw data. If the levels of two inputs are observed or manipulated to be uncorrelated, there is no need to be concerned with mediators of one input confounding the other input.

Learned horizontal associates

A particular sort of association of each of two associated events with a third event involves no causation between the pair of events. This includes the fundamental generality of each pair of the features of a particular object or situation. The third factor is previous exposure to the conjunction of those features. Neither feature has ever had any influence on the other. In theory of learning and memory and their neural basis, this type of coinciding between events has been called a horizontal association, to distinguish it from a vertical association between a cause and a consequence (Wickelgren, 1999).

One form of horizontal association is configuring. This type of performance is considered later below, within the broader context of interactions among response-stimulus functions.

Perceptual influence (SSR → R_m)

Perception as performance

We return now to mental process widely invoked in the interpretation of psychophysical data, which is distinct from conceptualization (R) and description (SR). This is mediation by a conscious process such as a bodily sensation or a visual image. The private experiences of such observable achievements are the philosophers' qualia (Chalmers, 1996). In an intentional or emotional process (SRR above), a response-generating concept (R) modulates a description (SR). In a perceptual process, a description (SR) modulates a stimulus-generated process (S) (Figure 7e).

That description may be of the same stimulus or a different one. When the response in an SSR process picks out a different stimulus, the modeled response is being controlled by some similarity between the two stimuli. Such performance provides evidence that the two sources of stimulation act through the same input channels, at least to some extent.

For example, the savory flavoring compound, monosodium glutamate (MSG), stimulates a class of receptors on the tongue for amino acids such as its glutamate component. However, MSG also stimulates the other four classes of gustatory receptors, not just sodium salts, but also sweet sugars, acids (tasting sour) and the neuron activating binding sites for at least some bitter compounds. The question therefore arises whether activation of the glutamate taste receptor can be mimicked by configural processing of information from the distinct affordances by a sugar, an acid and a bitter substance. When sucrose, citric acid and caffeine were mixed with MSG in naturally glutamate rich tomatoes, MSG proved to be on the same dimension as each of the other differently tasting compounds by their co-occurrence in a perceptual model (S_nS_mR) (Figure 8; Booth, Freeman *et al*., 2011).

Figure 8 about here

Causal theories of perception and intention: the unsituated brain

Perception is often thought of as a picture created by active neural pathways from the eyes or other senses. An analogous view of intention is as a picture of the goal object, which drives the contraction of muscles in the limbs or speech apparatus. This has been called destructive physicalism (Travis, 2012). Its logic presumes that the brain could work in a jar with no reference to situations outside the body within which senses and muscles work.

Yet nobody who has tracked through the brain from sensory stimulation to muscle contraction has ever seen a sensation, a concept or an act of will. This deficiency in neural reductionism cannot be rectified by a dualistic 'liaison' interface (Popper & Eccles, 1977) or any other theory of 'upward' and 'downward' causation between brain and mind. There is wide recognition -- though still far from universal -- of the infinite regressive fallacy of stimulation to the retina being transformed into pictures viewed in visual cortex (Hamlyn, 1957, 1990; Ryle, 1949). The same fallacy afflicts the assumption that the intention in an act causes the contractions of the muscles in the limbs or the larynx (Anscombe, 1971/1993).

What makes the anterior temporal gyrus function as auditory cortex is the discriminative performance enabled by its connection with sounds through the ear (Booth, 1978b), not subjective experience immanent in the local networks (Puccetti & Dykes, 1978). No consciousness of stimuli is possible without a culture of attributing states to individuals in the presence of such affordances (Wittgenstein, 1953).

Stimulatory influence (S → R_m)

The sixth and final type of processing to be described here is control of the modeled response by processing of stimulus information alone, without any mediation from concepts (Figure 7f). Nevertheless, a feature in the learned norm can be involved and so this stimulatory mental causation is not a sensory process (or apperception) driven purely by receptor activity.

This S type of mental process, together with the R and SR types, was considered by Booth and Freeman (1993) in the first formal statement of this approach. Such purely stimulatory influence was initially called 'direct' control of the response, because of the contrast with indirect control by a response/stimulus relationship (Booth & Freeman, 1993; Freeman & Booth, 2010; Mobini *et al*., 2011). The three deeper processes included above (SSR, SRR, RR) were included in the theory later (Booth, Freeman *et al*., 2011; Booth, Sharpe *et al*., 2011). One example of each of the processes is given in Figure 9 for a study with four stimuli, the response to be explained and three other responses.

Figure 9 about here

If all the hypotheses of covert processes have been tested and the overt response/stimulus function still accounts for the data best, the evidence overall is that the information from the source of stimulation acts directly on the response. The ambiguity with the conscious perceptual process (SSR) has been removed, as well as the descriptive (SR) and conceptual (R) interpretations of the psychophysical function. Since no monitored conceptualizing has been implicated, it is possible that the information from the stimulus has been processed unconsciously in generating the modeled response. It should be noted that the discriminative performance used in this criterion of consciousness is the detection of quantitative differences within a category, not a distinguishing between categories (Fisk & Haase, 2005). Also the awareness is not of the neural processes involved, nor of the cultural basis of the conceptualization; the 'inside view' is of the mental achieving, be it perceptual, descriptive, reasoned, intentional or emotional.

Unconscious mentation

There is a logically asymmetry between evidence for and against awareness of a stimulus. Attempting to show that a person is unconscious of a stimulus is trying to prove the null hypothesis. The most that can be done is to exclude all other coherent hypotheses. Personal cognition is exhaustively multi-thetic. Hence analysis of an adequately designed set of observations could show that the discriminative performance of all other processes was negligible on that occasion, whereas a response that did not involve a relevant concept had appreciable differential acuity for direct stimulation (Booth, Sharpe & Conner, 2011a).

Limited duration of exposure to a stimulus, as in priming designs, does not establish the absence of mediating conceptualization that could mediate discrimination or detection (Koulder & Dahaene, 2007; Snodgrass, Bernal & Shevrin, 2004). Failure of a specific concept (R_1) to detect the stimulus is insufficient to establish perception without awareness (Merikle, Smilek & Eastwood, 2001). Recognition (by R_1 explicitly) of the presence of the stimulus (S_1) does not exclude the possibility that the stimulus (S_1) is being conceptualized in another way, such as within one of the four other types of discriminative process specified above (R, SR, RR, SRR). For example, detection of other features (S_2, S_3 etc.) of the conscious situation (monitored by R_m) could have activated the concept of the undetected feature (R_1).

This design has been implemented for the integrative response of degrees of preference (R_m) for supposedly different brands of coffee; the only difference between samples of the individual's usual drink was the concentration of caffeine (S_1) added to a decaffeinated brand (Booth, Sharpe & Conner, 2011a). In about half of the participants, rated preference discriminated between levels of caffeine better than intensity of bitterness did, both before and after the term *bitter* (R_1). However, the concept of bitterness is implicit in the concept of coffee. Roast coffee contains bitter compounds in addition to caffeine. Strength and mildness of taste are features named on packs and a key concern in deciding how much coffee to put into a brew. Unsurprisingly therefore, for most participants, distances of bitterness from preferred norm had some discriminative acuity for the caffeine in the samples that were tasted before *bitter* was mentioned: the concept was in their minds from the start. Out of the 28 participants whose preference ratings discriminated caffeine better than their bitterness ratings, just two had negligible discrimination between caffeine levels by implicit bitterness (Booth, Sharpe *et al*., 2011a). Hence only about 7% of the apparently subliminal perceivers of caffeine might in fact have been unconscious of its taste before bitterness was mentioned.

Norm-zeroed discrimination scaling provides rich and precise analysis of factors in subconscious affect. The implicit association test draws limited conclusions from multiple tests of a great number of words provided by the investigator (Greenwald, McGhee & Schwartz, 1998; Roefs, Huijding, Smulders *et al.,* 2011).

What is it like to be you or me?

The distinction between stimulatory (S) and perceptual (SSR) processing illustrates a basis for showing how the consciousness of something is possible. It does not address the issue what consciousness is. Some philosophers regard that as an extremely hard problem (Chalmers, 1996). Certainly the issues are intractable if the scientific issues of how consciousness is possible are conflated with the artistic issues of expressing personal experience (Booth, 2003).

This game was given away long ago by the title of a key philosophical paper, “What is it like to be a bat?” (Nagel, 1974; cp. Hacker, 2002). If people wish to express what it is like to be themselves by writing or making pictures or objects, others may (or may not) be appreciative of experiencing their creations. The contents of consciousness are like such expressions into and from whatever reality the artist lives within (Wittgenstein, 1953). If bats are incapable of public comparisons of themselves with each other, a bat cannot compare itself privately with anything public, and so there is nothing (subjective) that it is like to be a bat. The present human reader and author may or may not have difficulties in expressing ourselves or appreciating each other. Nonetheless, our capacities for interacting with others provide good grounds for granting that we have self-identifying experiences to express.

Treatments of consciousness often get off on the wrong foot by presupposing an arbitrarily materialist metaphysics (Koons & Bealer, 2010). For example, a leading theorist wrote that “we have good reason to believe that consciousness arises from physical systems such as brains” (Chalmers, 1996, page xi). That argument, empty of evidence, leads to the view that “we are entirely in the dark about how consciousness fits into the natural order” (*op. cit*.). On the contrary, natural order includes human society as well as the human body, even though many natural scientists take no account of the mundane processes of communal culture that have become an automatic part of their lives. This ability of each member of a culture to share information with others on what she or he is doing can become highly integrated. That amounts to the agent being aware of what s/he is doing, including the perception, emotion and thought that is involved. Such awareness would normally carry some appreciation by the agent of being a unitary entity with some characteristic ways of acting. That is what it is like to be you or me.

Of course this is far from a full scientific account of the competence of being conscious of oneself in action, perception and thought. Yet seeking causation within the brain alone, or within society alone, let alone within consciousness itself, must be doomed to failure. Consciousness of a personal self is widely recognized as having differentiated from consciousness of other people but this remains an open question with apes (Call & Tomasello, 2008). They can learn to compare themselves objectively with others in some respects, e.g. by recognizing the image in a mirror as of their own body (Lin, Bard & Anderson, 1992). The person’s performance on any particular occasion is open to investigation, such as by norm-zeroed multiple discrimination scaling. How such a competence was acquired is a still further question for a new science of the development of the individual mind within that person's inherited social and biological endowments.

Integration among mental processes

Differences between features

We now move to considering the variety of interactions among the active causal functions within a mind. The default assumption is that information from different sources is distinct in its processing. Where two input patterns do not cohere to a sufficient extent, they continue to be processed separately, up to the point where one pattern of output to the environment is generated from the patterns from both the sources. Hence, to the extent that sources act differently on a sink, their distances from norm combine orthogonally into the size of that response. That is, the distances from norm of two features of each test sample should in the first instance be plotted onto separate stimulus axes, giving a two-dimensional (2-d) model. The resulting diagonal from zero to the pair of observed feature values provides projections for use to match the norm and the environment (Booth & Freeman, 1993; Sloman, 1993).

The ability to distinguish a difference in patterns from examples of the same pattern is not uniquely human, nor does it depend on language in human beings (Wasserman & Young, 2010; Young, Wasserman & Ellefson, 2007). Telecommunication engineers have long known that messages from different people can be transmitted simultaneously along the same physical cable using distinct carrier frequencies. The spatial separation between origins (or destinations) does not need to be maintained during transmission. Two separate channels could be operated over the same neural pathways in the brain, just as two data channels can transmit along one wire. It is the contents of information that are kept separate, not the locations within a physical medium. Distinct mental processes do not necessarily activate (or inhibit) different regions of the brain.

Two different words could be conveyed orally and aurally by the same sound. For example, the sounds for "eye" and the "I" could be identical in the utterance "I have an eye on you" but the meaning conveyed remains totally unambiguous. The same point has been argued against the idea that there is a labeled line through the brain for each taste; rather, the distinct patterns of afferent activity are distinguished (Erickson, 1982, 2008). The argument is no different for any material or cultural category. The medium is not the message.

In general, the channels of communication across the mind can be handled in a geometric model. Each channel can be represented as a Euclidean dimension. Hence whenever channels from distinct stimuli interact to influence an integrative response, the predicted output follows from Pythagoras's theorem as the square root of the sum of squares of distances from norm along each axis. This calculation, for orthogonally varying sources of information A and B can be represented by the formula A Ί B, where the right angle of the Greek capital delta (Ί) stands for the operation (for any number of distances) of adding the squares of the distances and then taking the square root of the sum. With a third affordance, C, the model becomes three-dimensional, A Ί B Ί C, and so on.

Dimensions within modalities

In physical science, a measure may combine quantities of two of more types of phenomena, such as space, time, force, mass, charge and so on. Thus the dimensions of force (F) in Newtonian physics are mass (m), distance (d) and time (t), or more precisely $m.d.t^{-2}$ (as in F = ma, where a is acceleration). This concept of dimension can be applied to modalities of sources of information in psychology. It remains to be clarified how this type of dimensionality relates to the dimensions comprising orthogonal discrimination distances from norm but so far they appear to be empirically identical.

Dimensional analyses of sensory modalities. Day vision was categorized as three-dimensional and night vision one-dimensional (Pugh & Kirk, 1986). That analysis of dimensionality was applied to pairs of sweet sugars (Breslin, Beauchamp & Pugh, 1996). These two examples apply to classes of sensory receptor -- retinal rod pigments and cones for vision, and lingual taste receptor types culturally categorized as sweet, salty, sour and bitter (Booth, 2008a; Booth, Freeman *et al*., 2011).

Nevertheless, a single dimension of mental processing does not have to have a simple biochemical or linguistic base. There is no reason to believe in pre-set neural connections from specific receptors on the tongue for sugar to a spinal network that contracts the muscles for uttering the English word *sweet* (and for marking a point under the written word) or to a cerebrocortical network that generates a private experience which can be expressed under the name of sweetness (Booth, 2008a). Rather the connection is learned during conversation deploying the communally agreed symbol for a taste shared by ripe fruits and honey (Quine, 1974; Wittgenstein, 1953).

Dimensional analyses of symbolic modalities. Ratings of affect symbolized in words or faces have long been resolved into the theoretical constructs of arousal and valence (Davits, 1969; Osgood & Suci, 1955; Russell, 2003; Russell & Mehrabian, 1977; Wundt, 1902). Emotional arousal particularly has been treated as having physiological components. Purely cognitive dissociation of arousal and valence has been achieved in grouped data (Kuhbandner & Zehetleitner, 2011). Nevertheless there are substantial variations among individuals (Feldman, 1995).

Individualized discrimination scaling has been used to test for self-conscious arousal and valence in the motivation to eat, expressed while viewing a color photograph of a familiar food (Galea, Chechlacz, Booth *et al*., 2008; see Chechlasz, Rotshtein, Klamer *et al*., 2009). Each of a large set of food items was rated for strength of that particular motivation, interest or excitement (arousal) and direction of affect (valence), i.e. degree of pleasantness. Of the individuals who used both concepts of arousal and valence to decide strength of motivation, a majority (63%) placed the two concepts on different dimensions (2-d models). Nevertheless the remaining large minority combined arousal and valence into a single dimension of desire to eat (1-d models). Furthermore a fifth of those who separated some aspects of the two concepts combined other aspects into a single dimension also (3-d models). Such findings indicate that, if all motivation is a combination of independent factors of arousal and valence, this is not universally evident in conscious processing. In this testing of desire for pictured foods, half the participants treated arousal and valence as wholly or partly the same in their involvement in motivation.

Discrimination dimensions are not latent variables

A response's concatenation of Weber fractions of stimuli is totally different both from a convergence between manifest measures of a latent variable and also from a correlation between responses, as in a principal component or multivariate. No measures of stimuli are involved in the multivariate modeling of patterns in responses or in the multimethod-multimeasure approach to validation.

More widely, there may be analyzable causation of concomitant events apparent in historical documentation or identified by grounded theory in narrative text (Glaser, 1998; Strauss & Corbin, 1998; Thornberg, 2012). In some instances, it may be possible to distinguish between candidate input and output events and then mount discrimination analysis on a 'pseudo-psychophysical' basis, with words or concepts as input instead of characteristics of materials (e.g., Booth *et al*., 2011a; Conner, Haddon & Booth, 1986b, under review/2013). It would be valuable to have side-by-side comparisons between norm-zeroed discrimination and conventional qualitative analysis.

Identity between features

Summation of distances

There is a single alternative to the default interpretation that two orthogonal stimulus features are on separate discrimination scales. To the extent that information from two sources is transmitted summate into a sink, their influences are combined in an indistinguishable way. In other words, the two sets of information are transmitted across that mind on the same channel. This is a unidimensional (l-d) cognitive model. Distances below the norm subtract from distances above the norm. For physical stimuli, with axis intervals being ratios of a physical measure, subtraction becomes division, while addition of discrimination distances is multiplication of physical measurement values. If the summations of the number of Weber fractions from norm in each stimulus from a test sample (A + B) accounts for more variance than the square of the sum of their squares (A Γ B), the evidence is that the stimuli A and B share a feature.

The environmentalist concept of stimulus equivalence (Sidman, 1994; Sidman & Tailby, 1982) corresponds to additivity of S models. Response equivalence has many meanings, from comparisons between cultures to technicalities of test construction (Johnson, 1998). If such a paradigm were made amenable to norm-zeroed discrimination analyses, one account of equivalence would be addition of R models.

With two stimuli, there is a third possibility beside the 2-d and 1-d cases. The stimuli might provide both in part the same information and also entirely distinct information. The channel summating the same information from two sources is separate from each of the channels transmitting two the distinct sorts of information. That is, this is a 3-d case.

Configuring in learnt personal norms

Some of the distinct features in a developing norm may become combined onto a single discriminative dimension. In addition to a response coming under the influence of a similarity between two stimuli, two disparate stimuli might gain control of a single response, for example if their co-occurrence predicted a consequence. If stimuli A and B are presented together, an initial 2-d model A΄I B could become the 1-d model A + B as a result of learning. Such 'horizontal' associations (Wickelgren, 1979) have long been studied in animal behavior.

Psychologists of associative learning have identified various ways in which stimuli can come to act together. If both A and B alone continue to elicit a response after training, and the response to A and B together is no greater than the sum of A alone and B alone, then A with B is said to be a compound stimulus. If neither A alone nor B alone elicits the response, whereas A + B does, then the compound of the two distinct features (A and B) has become a fully configured stimulus. This is configuring in the strict sense of developing a 'third stimulus' -- a unitary super-feature that influences a response, without its component features having any influence (Rescorla, 1973; Whitlow & Wagner, 1972). Nevertheless this criterion can be relaxed to allow for effects of categorical similarities between component features and the configuration (Pearce, 1994). This corresponds to a 3-d model, (A+B)΄I A΄I B, where the sum of the contributions from the simple dimensions A and B is less than the contribution from the complex dimension A + B.

This 3-d model can also show if there is genuine synergy. The usual criterion of synergy is a response to the combination that is greater than the response to either component alone (Birch & Campbell-Platt, 1994). However, response measures lack the scaling provided by response/stimulus measures, which is needed to distinguish synergy from exact summation or indeed from subaddition.

Testing among the hypothesized structures of mental processing

The best cognitive model

Much research focuses on testing a single hypothesis by analysis of grouped data. Norm-zeroed discrimination uses the data from each session with an individual to test among many mutually exclusive causal structures. That is, each piece of research in personal cognition tests a small set of specific hypotheses against each other on the whole set of data. The question is how much better one of the theoretically determinate structures fits the observations than any of the others. This contrasts with comparisons among large numbers of minimal hypotheses for exclusion of the null hypothesis (Shaffer, 1995).

Tests of degree of fit to data of hypotheses in personal cognition are based on the simplest possible procedure -- comparing models for variances accounted for in least-squares linear regression. In contrast to the estimation of values for Weber fraction and norm point that require slope and error, only the error is needed to evaluate the success of a modeled interaction among mental processes. Each such model has a single discrimination-scaled value for each variant of the tested situation. Simple regression from the hypothesized interaction to the response being modeled tests each addition of an element for increased r^2. This contrasts with multiple regression which tests the effect of adding an observed variable on the variance accounted for. The calculations also differ from path analysis and structural modeling, because all the hypotheses about mental structure are incorporated in the single value resulting from a cognitive model of the data for each sampled variant of the situation.

Sequence of calculations

Building complex single dimensions. The first step in search for evidence of interactions between discrimination-scaled response is to test each elemental model for similarity with each other elemental model. If the r^2 value for the sum of the two discrimination distances is greater than the r^2 for either element alone, the summation of those two elements (A + B) is accepted as closer to truth than either element alone (A or B).

The second step is to test each successful two-element 1-d model against the greater complexity of summation with the distances from norm for each of the remaining elements. If the three-element 1-d model has an r^2 value higher than each of its three two-element components, that model is validated for further testing. In a third step, if a four-element 1-d model (A + B + C + D) has an r^2 greater than the r^2 value of any of its four three-element components (A + B + C, A + B + D, A + C + D or B + C + D), it is accepted as nearer the truth on the available evidence.

Because increasing numbers of complex components all have to do worse than the model at the next higher level of complexity, iterations of this procedure rapidly converge on the best unidimensional model. Sometimes an element accounts for more variance than any of the summations with another element, leaving it as the only valid 1-d model. In other words, that person's norm recognizes no similarity to any other element in the tested variants of the situation.

Discrimination of similarity between stimulus elements is a powerful way of comparing the specificities of sensory receptors. Previous approaches to such dimensionality of a sensory modality have been mathematically complex and restricted in generality (Breslin *et al*., 1996, for tastants with unique purity of sweetness). The unidimensionality of sweet sugars has been confirmed by this method (Booth, Freeman *et al*., 2011), together with a single dimension of sourness, and its unique power to identify multiple dimensionality in a single stimulus (Figure 8, above).

Building multidimensional models. The second phase of calculation tests all the validated 1-d models for inclusion in multi-dimensional models, i.e. using the criterion of the square root of the sum of all those 1-d models' square of each sample's distance from norm. The logic is identical to that for validating complex 1-d models. The r^2 of the model having one more dimension is tested against the r^2 for each of its component models. The model with the additional dimension is only accepted for further testing if it accounts for more variance than any of its components. Such increasing dimensionality converges for the same reason as complexity of 1-d models. In experience of this approach so far in situations with up to five stimuli and six responses, 4-d models have been rare, and 3-d models in a minority.

Restriction to elements of the same type

Each series of calculations that increases the explained variance can be restricted to interactions among discrimination-scaled elements of identical type, e.g. all S or all SRR. This protocol corresponds to a theory that attention is focused on one sort of task at a time. The modeling converges on each type of process separately. Usually in work to date, the best model for one type of process accounts for considerably more variance than the best model of any of the other processes. Experience thus far also is that opening up the calculation to all processes generally yields only small improvements in explanation by the best model of a single type. The potential theoretical significance of such patterns of evidence is considered below in the context of examples of cooperative action.

Differences between individuals

One set of stimuli presented in a fixed sequence can be processed quite differently between individuals. It is not surprising that people vary in their ways of addressing a situation. In order to read a mind on an occasion, the investigator and participant need to interact. Yet the design of the investigation need not prevent the participant being herself or himself.

To illustrate, an experiment using purely verbal stimuli and responses provided a striking contrast between two individuals. This pair of cases also illustrates the SRR and SSR types of process. One woman and one man identified themselves as those who "crave" chocolate on occasion. Eight portions of food were described in turn and rated for how much each was craved, and how calorie-rich, healthy and chocolatey each portion was. Two levels of the four attributes were varied across the eight descriptions with only small correlations between them.

Both participants gave 2-d models with complex dimensions (Figure 10). However, one used SRR processes and the other had a SSR model. The gender is unspecified because one datum provides no logical basis for generalizing. (Thus any stereotyping by the reader can have full reign!)

Figure 10 about here

Each participant's retrospection on the experiment was similar in the relative salience of concepts. Some specifics of interpretation of the models were illuminated. This illustrates the close relation of conceptualized performance to phenomenology. Yet there is no direct relation between a concept and a feature of the material world (*qua* Fechner) or a region of brain activity (as phrenological versions of neural reductionism require).

The investigator as another mind – or the same one

This approach to psychology tests multiple interpretations or hypotheses on data that are collected in contexts that are selected to be relevant. Study of the workings of a mental system is joint performance by investigator and participant that is in principle public. The investigator is another embodied and acculturated system who also attends actively or reactively, learns and remembers, and perceives and describes. In particular, an effective investigator makes records that are comprehensible by others who are equally familiar with the context of the investigation.

All the above could be done by a participant who has the competencies of an investigator. Hence at the start of some lines of research, it may be possible for an investigator to meet these conditions for effective investigation while also being the participant (Booth, 2004).

Joint intention, fellow feeling and empathic perception

Cognitive-affective-conative processes of acting jointly

The psychology of cooperating with and helping others continues to be dominated by multi-item questionnaires focused on the phenomenology of empathy and sympathy, despite the recent rise of experimental analysis of interpersonal performance. The inventories' subscales purport to distinguish between cognitive and affective aspects but in terms of what respondents feel, rather than how well they perform (e.g. Davis, 1983, and many updates). The psychometric approach also focuses on traits with little specification of the situations in which they are expressed. The experimental approach seeks to characterize capacities using specially constructed test situations. Neither approach is suited to explaining ordinary helpfulness and cooperation, or designing ways to encourage such practices.

Multidimensional norm-zeroed discrimination points to a new sort of experimental psychometrics, based on the causally most powerful features of interpersonal performance in commonly occurring situations. If there are personal and situational traits of empathic cognition and sympathetic affect, they should emerge from generalizing across individuals and scenarios.

The inputs to ongoing mental processing are signals from the other person and the context. The outputs are expressed responses to the situation. The psychometric distinction corresponds to the attribution of rationally intentional and/or emotionally reactive meaning to the interpersonal situation, i.e. motivation to help or cooperate and feeling compassionate. This is a distinction between sorts of concept (R) driving the description (SR) in the SRR processes in Figure 11. Empathy is more than that: it involves perceiving (or even undescribed sensing) of the other person's part in the situation. Perception of need provides a reason for acting and may fuel both distress and concern in the perceiver (Figure 11).

Figure 11 about here

This network model of mental processes in situations for helping or cooperating raises question about the interpretation of outcomes of discrimination analysis. Interacting all the processes, regardless of type, could put a pathway of causation onto a single dimension, and different pathways on separate dimensions. If the calculations restrict interactions to one type of process, then the best model may represent the one focus of attention, such as distress at the need of the other person or a conflict between reasons for acting in the specified situation. However, that interpretation would not be secure unless the best model accounted for most of the variance in the intention to act. If it took two or more models with different types of process to cover all the variance, then the possibility should be considered that they are both or all active. Indeed that interpretation would be supported if the best unrestricted model combined the two types.

Example of disposition to help

Many recent experiments on helpfulness, such as donating to charity, use the amount of money contributed as a measure. A survey might estimate the outcome of an appeal but cash response introduces extraneous variables such as available income. A theoretical understanding of helping is better based on disposition to help, when assessed without distortions of linear response-stimulus relationships.

A simple illustration is provided by responses to vignettes of an appeal for donations towards a wheelchair for a person with limited mobility. The three stimuli varied independently across vignettes were severity of the disability (S2), cost of the wheelchair (S1), and the availability or not of a subsidy (S3). Participants rated each vignette first for the likelihood that they would donate any cash (R1) and then how great the need was for a donation (R2) and how bad the disabled person felt (R3).

The best model for a majority of participants included both rational and emotional factors in willingness to donate. For example, one two-dimensional solution ($r^2 = 0.91$) added the rated need (R process) to the disabled person's distress at their disability (SR process) on the dominant dimension and had just stimulation from the cost of the wheelchair (an S process) on the other dimension. Since perceived need was similar to perceived distress, that major dimension might be operating affectively. Therefore this model could be evidence for the emotional and intentional pathways running in parallel.

Another participant also had a 2-d model as the best ($r^2 = 0.85$) but both dimensions appeared to be rational, perhaps about the assessment by the expert advisors to the supplier of a subsidy. The subsidy was the major dimension and the disability the minor one. Two SSR models tied with that S model, each applying one response concept to both the stimuli. This was the rated need in one model and adjudged distress of the disabled person in the other. This may indicate that an affective pathway was operative but within the context of a rational deferral to expert opinion. A third participant appraised disability (more) and cost (less) but with affective and rational routes on the same dimension, both distress and need conceptualizing cost on the same dimension ($r^2 = 0.91$).

These diagnoses of individuals' mental processing while considering an appeal to help a person are encompassed by the outline theory of empathy and compassion (Figure 11). This illustrates how norm-zeroed discrimination scaling of perception, emotion, and action with reasons, can outdo both the scoring of individual differences on situationally under-specified psychometric subscales, and also those experimental tasks that are limited to testing particular hypotheses one at a time on sets of individuals. If there are stable differences between people in the power of different features of joint intention across situations, they will be found in data from life. Indeed, if actual occasions of help and cooperation have commonalities in their stimulus and response features, then situations will be shown to have traits too (Bem & Funder, 1978). The same principles apply to the norm-zeroed discrimination of socio-effective signals from movements of the face (cf. Calvo, Fernández-Martín & Nummenmaa, 2012).

Determinacy *versus* loose parameters

Parameter-free fitting to data

The theory of discrimination-scaled distances from norm yields an arithmetically determinate equation for the effects of each salient feature and its potential interactions with other features. The direct approach is to measure the stimulus quantities for features that are in common among the objects to be tested. Such measurements may not be readily available, however. In some cases, they may even be impossible in principle. Nevertheless, an indirect approach is also feasible. Quantitative judgments specific to each affordance can serve as surrogates for the direct measure of that stimulus, so long as those responses are validated by consensus among participants.[2]

[2]Procedures like this are in wide use but not set within the psychophysical framework expounded here.

For example, each participant can be asked to name the characteristic features of a first sample of a category of objects. Additional feature names may be elicited by subsequent samples in that category. Each person's list usually ends within two or three samples. Those names can be used to assess the strength of each feature in quantitatively assessed samples. Means across participants' normally distributed scores can serve instead of physical measurements in the same participants or, better, in other participants living within the same social and material environment (e.g., Conner, Haddon & Booth, 1986b, 2013/under review; Freeman, 1996; Freeman & Booth, under review; Mobini *et al*., 2011).

Other common approaches invoke loose parameters, with values specified on the criterion merely of better fit to data. The enterprise is presented as a search for high level scientific principles (Stevens, 1961; Shepard, 1987, 2004). In the end, it offers no more than highly degenerate hypotheses. Even though the fitted function is elevated to the status of scientific law, the numerical values of its constants are not treated as a critical empirical issue. The scientific approach would be to state a theory that implies a limited range of values for each constant, and then to test that hypothesis on diverse new data.

Power functions with loose exponents

Fechner's mistake of ignoring the increases in Weber's fraction at low and high levels of stimulation was compounded with two additional errors by S.S. Stevens (1957, 1961). First, instead of providing two response anchors within the range of Weber fraction constancy, Stevens presented an arbitrary initial stimulus level and used the number the assessor assigned as the sole anchor. The second error was to assume that instructing the assessor to assign ratios of that anchor to subsequent test stimuli gave numerical ratings that were in ratio and therefore could be transformed into logarithms without any mechanistic justification. Stevens replaced Fechner's graph of logarithmic stimulus values against responses with logarithmic response values, to give a log-log plot. This is a power function in its linear form. The slope of the fitted straight line is the power exponent.

Such tinkering with response values is questionable because those are the data to be explained. Furthermore, taking logarithms of both variables moves almost any shape of a monotonic function closer to a straight line (McBride, 1985). One exception, ironically, is a semi-logarithmic function, such as the Weber-Fechner equation. What saves some data from favoring ratios of only medium stimulus values is an extreme value which could have been biased by the instructions to respond in ratio. Hence a power function should only be fitted to data when it does better than more specific functions, such as linear and semi-logarithmic (e.g., Newman & Booth, 1981).

A power function without any theoretical specification of the exact value of its exponent is nothing like a scientific law on the model of physics. The intercept of a power function has no logical meaning. In short, the postulation of a power law for psychophysical functions is a highly degenerate hypothesis.

The first steps in scientific testing of power functions in psychophysics would be to confine ranges to Weber fraction constancy, to show that the exponent from each set of data differs reliably from one in the same direction, and to replicate any departure from unity. Then those data should be tested for difference from the consensus among previous estimates for that modality.

However, an exponent less than one can be generated by at least three factors extraneous to modality. Merely the investigator's choice of physical unit can halve the exponent (Myers, 1982). Wide ranges of stimulus levels rated in ratio are liable to produce numbers that extend up or down by hundred[th]s; ratings that go across decimal orders are likely to lower the slope of the power function because of compression bias across decade orders. Levels of the stimulus that extend both above and below Weber fraction constancy will produce lower exponents than stimulus ranges that go only above or only below. Hence the values of the exponent of a straight line fitted to a log-log response-stimulus function are bound to be sensitive to variation among ranges of stimulus levels (Teghtsoonian & Teghtsoonian, 1978).

Exponents greater than one have been seen for some stimuli like electric current. That could be because the assessor changes the meaning of the quantitative responses at high levels of stimulation. Attention is no longer on the strength of prickles from the current. Instead the ratings jump upwards to express pain, or fear of electric shock. Assessors must be allowed to provide alternative descriptors and discrimination functions compared with rivals for the ratings on each concept.

Psychophysicists should never have sought a single equation to cover responses to all levels of stimulus. Weber's fraction and Fechner's constant stimulus cannot be ignored. If the design of an experiment allows increases in the fraction and switches in the implicit standard, such anomalies must be identified and accommodated in the analysis of the data. Evidence is needed on which mental processes transform the stimuli into the responses. Hence, the psychophysical equations have to test among the theoretical possibilities. Furthermore, response-stimulus relationships should be tested in contexts in which the previously evidenced cognitive mechanisms can work. It should not be possible for psychophysics to become isolated from mainstream psychological science.

The poverty of the theory-free psychophysics is further exposed when combinations of stimuli are considered. Experimentally varied mixtures of tasted or smelled compounds have been studied extensively. Rated intensities are generally suppressed by mixing. Yet the degree of suppression is described by a cosine, with the angle contingent on fit to the data (Cain *et al*., 1995). Another approach is to compare shapes of stimulus interactions in the integrative response between additive (parallel plots) and multiplicative (fan plot) in ANOVA (Anderson, 1981). This also is a data fitting approach without a base in mechanistic theory.

Loosely parameterized object recognition spaces

The psychology of the recognition of objects has a worse history than psychophysics. There has been the same preoccupation with grand abstract laws, supposedly imitating physics. However, the basic principles of classical, relativistic and quantum physics cover the quantitative minutiae of observed relationships between the conditions of observation and the observed consequences. Models of object recognition include only responses to objects, treated as unspecified categories. The models include no data on the stimuli, even the categories of their features, let alone the quantities as in psychophysics. Indeed, an early proposal that the distances between objects depended on features that they shared was dismissed as quantitative (Shepard, 2004, citing work in the 1960s published as S. Russell, 1988). Yet the distances inferred from responses are quantities, even though constructed by non-metric modeling. Indeed, the responses themselves are quantitative too, such as degrees of dissimilarity. Yet Shepard (1958, 1965) was one of the first to exploit the psychophysical identity between what the behaviorists called generalization of learned responses to a stimulus and what is rated by human subject as similarity between two stimuli. The tradition of ignoring the specifics of stimuli runs deep. In a reconsideration of relations between objects and features, the matching of feature levels to norm was discounted as applicable only to features presumed (erroneously) to be innately intensive (Lockhead, 2004).

In addition, object recognition models suffer even more than Stevens's power law from the degeneracy of underspecified parameter values – sometimes as many as four parameters (e.g., Lamberts, 2000). Such models can be adjusted to fit almost any data, without taking any account of the specifics of the tested objects and their features. They are empirically very difficult to distinguish from other models of response patterns, such as random sampling of features in the implicit norm (Nosofsky & Palmieru, 1997).

For example, controversy has raged over a key parameter in models of dissimilarity, namely the order of Minkowski space, e.g. two (Euclidean) or one (city block). Worse, non-integer orders have been proposed, such as between two and three, as though the theoretical meaning of the best fitting formula was of no concern.

Many sets of data showed a convex downward pattern. This was postulated to be exponential and that interpretation elevated to a general principle (Shepard, 1987). Yet the data were not subjected to analysis for the values of exponent(s). Furthermore, objects that are hard to discriminate give convex upward functions (Nosofsky, 1986).

Even if all the parameters' values in a model of responses generalized across diverse sets of data, such a model would remain an unprincipled fix. The need is for evidence on the likely complications of judging similarity when some features are shared, and when the shared features vary across pairs of objects. To make adequate contact with psychological reality, the modeling of patterns in responses needs to be augmented at the very least by identified categories of feature.

Probability *versus* content

The distinction between the slope and variance of a psychophysical function has profound implications, not only for psychological measurement, but also for all information science and engineering. The quantitative relationships of responses to stimuli specify the content of the information that is processed. The interactions (illustrated below) between the mental processes producing each observed response-stimulus relationship specify the basic structure in which that content is organized. In contrast, amount of information (number of bits) is simply the inverse of entropy or the amount of randomness (Shannon & Weaver, 1949). The number of bits transmitted or stored implies nothing about the meaning of the message or the content of the memory, or about the way that the information is structured (Garner & Hake, 1951).

Probability distributions have been used in an attempt to quantify the whole of the information being processed in a mind (Tononi, 2008). However, scaling only in probabilities does not encompass the structured content of the conscious or unconscious processing. The distances have to include the categories and amounts that have the probabilities. Weber's fraction as the unit of distance includes the slope as well as the variance.

The complexity of information processing in a system has been interpreted as causal density (Seth, Barrett & Barnett, 2011). However, the proposed measure of complexity accounts only for the amount of information. The specification of a causal process includes the slope of the effect-cause function, not just the variance it explains. Measures of the content and structure of the information are needed in addition if the density is to be of causation, not merely a derivative of entropy.

During integrative responding, the conditional probability distributions for the component stimuli can be tested for closeness to statistically optimum combination (Ernst & Banks, 2002; van Beers, Sittig & van der Gon, 1999). However, such probabilistic analysis of sensory integration does not elucidate its mechanisms. Indeed, Bayesian approaches are subject to the general criticism that they neither generate nor take account of process theory (Jones & Love, 2011).

Furthermore, it is recognized that learning is required to integrate commonly used experimental stimuli (Ernst, 2007). A learned combination of stimuli can be structured as a single configured stimulus, functioning as distinct from its components. In such cases, the statistical properties of each stimulus in the learnt combination no longer contribute to the integration (Booth, 2013). Hence good prediction from the Bayesian priors for the different sources of information may in fact indicate a lack of integration in any mechanistic sense of the term. The test combinations may be too artificial for a well integrated norm to be learned during the experiment, or at best until the later stages (cp. Stewart *et al*., 2005).

The pseudo-social fog of 20th century psychology

The name of the scholarly discipline of Psychology originally meant knowledge about the mortal human soul (a word still extant in cliché, such as *S.O.S.*, and *the life and soul of the party*). In modern terms, that means the systematic empirical study of the individual's life or, more specifically, of a person's mental life. Yet, for almost a century now, academic psychology has mostly studied quasi-social artifacts. These are generated by analysis that starts by lumping together the data gathered from individuals. No evidence is gathered on potentially relevant prior social interactions among the individuals studied. Hence the 'grouped' data do not relate to any psychosocial reality. At best, the investigated set of individuals is selected to be a representative sample of mutual strangers from a specified population. So the results for the 'group' may bear no relation to what is going on at the level of an actual group in the population. Indeed, none of the individuals generating the data may be at the experimental mean value or making use of the psychometric consensus construct.

This lumping of raw data across individuals began with the use of correlational statistics to give scores to individuals on scales created from answers to items in questionnaires (Spearman, 1904/1987; Nunnally & Bernstein, 1994). The focus on lumped data became effectively a universal requirement half a century ago, when the assignment of the variance in responses to features of the test situation presented at two or more fixed levels was adopted by experimental psychology from agricultural science. As a result, minority patterns are ignored. In questionnaire scaling, much more powerful individual differences may be lost in the search for the lowest common denominator of consensus. In experimental work, the theoretically most important results may be in those who go the opposite way from the central tendency, even when the mean difference between conditions is reliable.

Nevertheless, the scientific viability of experiments on individuals is recognized in journals of psychophysics. Interpretation of individuals' data has also been a strong tradition in the experimental analysis of the control of rates of a response by environmental contingencies. In both these parts of psychology, consistency among findings from two or three individuals is required but the individuals are not scaled and the size of an effect is not estimated from grouped data. Furthermore, the interpretation of coherence in an individual's extended verbal expression is a well recognized scholarly procedure in the movement that goes by the name of qualitative psychology. The data that should be combined or compared across individuals are their own characteristics of performance, not the unanalyzed observations.

The same principle applies to the scenarios on which individuals are measured. Research based on the cognitive contributions of features shared among situations would generate a fully situated psychometrics.

Part Three

How a mind works.
III. Development of an acculturated and embodied human life

Abstract

Learning is specified as a change in the norm induced by exposure to a related incident. Development is treated as the acquisition of structure to the content processed as a disparity between present and past.

Causation within a mind

Mental processes as causal

An event is being causative if it is influencing another event (Mumford & Anjum, 2011). Hence, if a mental process is the influence of one pattern of information on another informational pattern, this is a cause-effect mechanism. An observable action or reaction constitutes evidence that there is some mental causation generating that overt output. When such a response varies consistently with observable variation in a stimulus, there is more specific evidence about causal processes in that individual which have transformed input patterns extracted from the environment into output patterns injected into the environment. Mental causation has a place alongside other causation in current philosophical analyses (Maslen, Horgan & Daly, 2009).

Gibson (1966) distinguished between the source of information in the environment (an affordance) and the information extracted from that stimulus by the perceiver. Similarly, a distinction needs to be drawn between the information processed by an agent to generate a response and the affording of that response by the environment (Gibson, 1979). The mental event that accounts for the performance of an action is an intention (Anscombe, 1957, 1971/1993). To the extent that the response comes instead from a meaningful involuntary reaction, the determining mental event may be an emotion.

It should be noted that the causality of a mental process is not a representation of a causal process in the environment. The occurrence of mental causation is totally distinct from a person's attribution of causation to aspects of the environment. The mental processes mediating the perception of causes will be causal, but so will be the processes mediating other perception and all other sorts of public achievement and private experience.

Mental causation should not be equated with physical causation, such as that within the body and brain, or with social causation as within a community's culture and language (Cartwright, 2004; Casini, 2012; Godfrey-Smith, 2009; Psillos, 2009; Reiss, 2011). How people's own social and bodily lives relate to their mental lives will be considered briefly in this the third paper in this series, in the context of the science of individual development.

Evanescence of active causation

Causal powers and susceptibilities may be actuated transiently, rather than continuously without start or finish. An event is an active cause only for the period of time during which its influence is operative on another event. Such a causal process cannot be directly investigated before it has begun or after it has ended. These points can also be made in terms of the persistence of the influencing and influenced events.

Quantitative characterization of a particular causal process requires a series of tests at different levels of the source of the influence over the effect. These tests have to be made either during an active period that lasts long enough or in a set of periods during which the same temporary process is re-activated.

This requirement can be satisfied in investigations of sets of participants, by conducting one test or set of tests in each person and varying the levels of the influence(s) among people. In contrast, when causation in one person at a time is being studied, the repetitions have to be across a single session of data collection. Also, that session has to be short and stable enough for the active causal processes to continue or to be reinstated without change at each test. If a process or the active structure of processes does change, only the tests with self-consistent results will help to characterize a particular set of the processes that occurred.

Consistency within an individual across sessions also needs to be examined. Sessions some time apart carry increased risk of a change in the dynamics of the individual's performance. Nevertheless, an individual may be totally self-consistent across recurring occasions of a particular situation. Degrees of self-inconsistency may be compared among individuals or situations. Inconsistency within an individual or situation is distinguishable from random variation in the usual way, by comparison with inconsistencies among a variety of individuals or situations respectively.

Causal strength is differential acuity

On this account, the mental causation that mediates the effect of a stimulus on a response is identical to the discriminative process of the response's sensitivity to differences in level of the stimulus. The two conceptualizations are simply the logical inverse of each other. The apparently contrasting interpretations depend equally on the evidence that differences in a response relate to differences in a stimulus.

Hence the strength of influence of information extracted from the environment on an individual's entering of information into the environment can be measured as the discriminative sensitivity of that response for that stimulus. If a response's discrimination between stimulus levels can be estimated rapidly and non-invasively, that differential acuity provides a basic measure of the salience of that stimulus, and indeed is evidence of some form of attention to it. At a particular time, the finer the present discrimination between levels of a feature of the situation, the greater is the salience of that feature to that response by the individual. Evidence of current lack of attention can come from momentarily poor discrimination between levels of a feature which are distinguished well on other occasions.

Of course, additional evidence is needed to separate a lack of effortful attention from the failure of a feature to grab attention involuntarily. The explanation of the inattention under those conditions is also a matter for further investigation: is it distraction, masking by other features, known irrelevance, a neural interrupt, or what? The present approach provides a measurement of degree of attention which is independent of the indicator response and the matter attended to, as well as of the factors accounting for salience.

Symbolic responses and stimuli

Material and social environments *switch headings with above within part 3*

The mental events subjected to causal analysis may use information from physical quantities such as duration, distance or energy. Alternatively, the stimuli and responses may be cultural symbols, such as words in sentences, icons within a conventional display, and gestures or other non-verbal actions (Pollio, 1974). The symbolic information has meaning and can convey knowledge and so is often called semantic (Medin & Barsalou, 1994). Within the subculture shared by a research participant and an investigator, the pressing of a reaction time button is a symbolic act. Some environmental changes are polysemic, containing both cultural and physical information. Examples include facial movements, the tone of voice, presenting a picture, logo or signature tune, or the wearing of a perfume or style of clothing or haircut.

In other words, the sources and sinks of the information transmitted by a mental process can be categories and quantities either of sensed and moved material characteristics of objects and situations, or of symbolic attributes of cultural systems, conveyed in language, graphics or other media.

Physical stimulus ratios imply symbolic stimulus intervals

The quantitative responses of interest to Fechner (1860) were in verbal categories, while the stimuli were material. The linearity of Fechner's equation depends on the stimulus axis being in logarithms of a physical measurement of the quantity of stimulation, i.e. equal ratios of the material measure on equal lengths of the axis. However, the verbal categories also can serve as stimuli, with either verbal or physical responses. The semi-logarithmic equation for a material stimulus and a verbal response implies that verbal stimulus quantities should not be converted to logarithms but should remain on the stimulus axis as equal lengths (intervals) for equal differences in symbolic quantity. The argument is as follows (Booth & Freeman, 1993).

Consider the psychophysical functions for two different quantitative verbal responses to the same material stimulus, e.g. felt pressure on the skin and discomfort, or ratings of the pinkness of a rose petal and of familiarity with the variety of rose. Both responses are linear on equal ratios of the physical measurement of the stimulus. Therefore each of the two responses will be linear on equal intervals of the other verbal category as a stimulus, e.g. the discomfort from a felt strength of pressure or degree of familiarity with a rose having a particular hue.

Social and material realities

Psychological research has been diverted and distorted by the foundationalist fallacy within empiricist philosophies -- namely, that all knowledge is based on subjective experiences relating to material sources of input to the senses. The meaning conveyed by a symbol cannot be reduced to material stimulation or responding. Rather, the cultural system within which the symbol works provides a great variety of functional relations to societal as well as physical processes (Quine, 1974). Some words in a language are names for entities but, in general, sentences are not pictures of realities in the mind, the brain, the community or the material environment (Wittgenstein, 1953; cf. Bloor, 1983). Hence, conceptual processes cannot be grounded in sensory processes (Barsalou, 2008). Indeed, it is hard to see how sensory information could reach consciousness without grounding in conceptual processes that are shared in a culture (Wilson-Mendenhall, Barrett, Simmons & Barsalou, 2011). The stimulus equivalence classes of the radical behaviorists are indifferent to materiality or sociality (Sidman, 1994).

Hence, the productive research questions are quite different from such issues. What functional contribution in the individual's performance does the sensed information make to the concept, and conceptual information make to the sensing? Have sensory and conceptual inputs been configured by the individual into any of the physical or symbolic responses to the tested situation? How does such variety of mental performance come into being in a human person?

In broad terms, learning during development builds environmentally afforded norms for both the sensed characteristics of material objects and the culture's symbolic attributes of any recurring entity. Rather few exemplars can be sufficient for inferences from probability distributions (Shi, Griffiths, Feldman & Sanborn, 2010; cp. learning from new mixtures of odorants: Booth, 1995). Hence each newly presenting situation is likely to activate one or more personal norms that have already been built from potentially relevant categories and levels of features. On the theory of norm-zeroed discriminations, this acquired capacity has determinate mathematical and observational specifications. Some general implications of this approach are now detailed.

The autonomy of mental processing

Integration of biosocial features into object recognition

In order to recognize an entity in the environment, information from physically or socially distinct sources has to be brought together in the mind. However, such integration of information does not need to be a mental process separate from the achievement of recognition. There is no need to invoke some faculty such as attention to do the integrating. Rather, attention to features of the object is another way of describing the processing of features that are integrated within the norm for that object in situations like that pertaining. That is to say, the integration of features into the perception of the object is neither a bottom-up stimulus-driven process nor a top-down attentional process. The mental processing involves both memory and perception at all levels. Use of the learnt norm is afforded by the environment during input and affords the environment during output.

Of logical necessity, the features that constitute an object or situation have to be connected together, whether by configuring or some other type of integration (Booth, 2013). Therefore it tells us nothing extra if we find connections in the brain between afferents that transmit information from each source, or connections in the language between the individual's verbal concepts.

The questions that need answering first are psychological, such as whether an object's features are partly or wholly configured. Responses demanding analytical tasks, based on differentiations and similarities among norms for distinct objects and contexts, may or may not have different sensitivities to the features that were configured to carry out the integrative task. The answers are unlikely to be generalizable among people who differ substantially in relevant previous experience.

Non-mental bases of feature integration

Information from different stimuli has to be exchanged mentally if that incoming information is to be integrated into a response. Such mental processing requires activity in connections both within the brain and within the community. Which neural and cultural connections are used by the mentation has been developed during prior learning of norms for discrimination. Connections are strengthened and/or weakened during an individual's configuring of a norm, and during any differentiation from other norms. This dynamism of the learned norm during perception has its correlates in the brain (Imagoglu, Kahnt, Koch & Haynes, 2012). Its cultural correlates are simulated in experiments on the creative integration of features as rumors are spread (Bartlett, 1932; Garro, 2000)

Neuronal and cultural basis of learning

The neural basis of the learned multi-featured norm consists of interconnected adaptive synapses which are sparsely distributed (Kanerva, 1988; Linhares, Chada & Aranha, 2011) within the feature-specialized neural pathways (Booth, 1967, 1973; Uttley, 1970, 1976). Hence the activation of a region in the brain by the sensing of different sources of feature does not add to knowledge if convergence of the afferent synapses on cells in that region has already been shown. Regional activation shows only that the afferents reach the same region, not that they are connected. Even if they are connected, the question remains which sort(s) of integration those connections take part in. Evidence of the formation and breakage of connections leaves open what information is transmitted by such changed connectivity (Kourtzi & Conner, 2011).

Similarly, conceptual connections in a language imply nothing about speakers' mental processes (*pace* Whorf, 1956). Evidence of changes in linguistic usage leaves open what any individual has contributed to such cultural change, and what the changes have contributed to a person's thinking. The new verbal responses to a changed situation may strengthen or weaken an existing historical tendency. On occasion, the individual's development initiates a cultural change. A routine aspect of individual development is a cultural truism and makes no difference to the society, except as a stabilizing factor.

Neural binding between features

The erroneous materialist reduction of mind and its causal theory of perception generate a pseudo-problem. If one assumes that the stimulus features of an object cause neuronal activity in specific sensory regions of the brain, the question arises how such activity is 'bound' into the neuronal activity causing the multi-featured percept (e.g., Wolfe & Cave, 1999). Non-causal theory (such as here and in Gibson, 1979) does not separate memory from perception. The physical machinery for recognizing environmental entities by matching to acquired multiple featured norms can operate in automatic mode or be exploited by effortful analysis into features and search for their conjunctions. For example, the determinate norm-zeroed discrimination of integrated features can provide a basis for probabilistic strategies (Vul & Rich, 2010).

Norm-zeroed discrimination also helps to reconcile generic with specialized theories of the recognition of locations (Jeffery, 2010; Pearce, 2009). For example, a norm for a location based on visual and tactile cues, or olfactory and kinesthetic cues, could be acquired by general associative principles but perform as a specific spatial configuration.

Cultural binding between features

Social reduction implies that connections in the language are needed to bind features in the mind. Yet it is clear that language is generative. Furthermore, verbal expression can be incoherent.

Contrary to minds being societal constructions, symbolic processes in a mind can provide meaning to the culture, as much as affordances in the culture permit the output of information from mentation. 'Top-down' influences of historical context interact with 'bottom up' effects of communicating to others, within mental processing that cannot be reduced to or explained by the linguistic specifics or other events at the societal level (cp. Broesch & Hadley, 2012).

Synesthesia and its development

Crossmodal triggering

In synesthesia, a specific sort of stimulation in one sensory or symbolic modality evokes a discrete experience in another modality without any corresponding stimulation. Examples of synesthesia include the experiencing of color on seeing a letter of the alphabet, or the thought of a number, a letter or a day of the week when viewing a colored object (Rich, Bradshaw & Mattingley, 2005). A particularly instructive case of seeing colors in letters was tracked back to specifically colored letters in a set of refrigerator magnets seen frequently as a child (Witthoft & Winawer, 2008).

Nevertheless, a case of synesthesia can be hard to explain in terms of likely previous circumstances. That may simply be because of the difficulty of identifying specific events in early childhood that are potentially relevant. The original source of a lexical trigger may be particularly hard to identify (Simner & Haywood, 2009). Yet it is easy to guess why a native English speaker might see yellow in the letter Y (or a French speaker in J), and blue in B (French too), although seeing brown in D is harder to puzzle out without knowing more details of the individual synesthete's cultural background.

Basis in biology and society

This striking phenomenon illustrates how neither a neural basis nor a cultural basis can stand on its own in psychological development. Neurogenetic expression and linguistic education interact in early life to select contrasts among material and symbolic affordances of environmental entities. Idiosyncratic development of those feature identifying processes accounts for synesthesia and other unusual sorts of crossmodal integration, alongside the unremarkable integration of abilities and experiences that underpins everything that we do.

A variety of evidence indicates that the source of synesthesia is an unusually configured norm acquired early in life. Synesthesia like effects can be acquired in adulthood, but these may be the potentiation or specialisation of features in universally long established multimodal norms. Instances of synesthesia in a dramatic form are relatively rare (Rich *et al*., 2005). It has been claimed however that such crossmodal effects are common for odors (Stevenson & Tomiczek, 2007; Stevenson, Rich & Russell, 2012). Generic theory of biosocial mental development can account for the acquisition of widespread crossmodally configured generalization, as well as extreme synesthesia in special circumstances.

Some common forms of cross-modal integration might be regarded as illusory and yet they can be accounted for as re-integration of differentiated features. For example, the locating of a food aroma in the mouth rather than the nose could result from the integration of olfactory, gustatory, and spatial (tactile and conceptual) information into the identification of the food actually present inside the mouth (Lim & Johnson, 2012; Rozin, 1982). Thirst-quenching properties are attributed to the colors of drinks which vary in acidity (Labbe, Almiron-Roig, Hudry *et al*., 2009). In part at least, this could be color-food name mediated form of lexical-gustatory synesthesia (Simner & Haywood, 2009). It has been proposed that this norm of perceived water repletion includes tactile information from the saliva that continues to be secreted after the swallowing of acid (French, Read, Booth & Arkley, 1993).

Within the biological system underlying a mind, excitatory connections among neurons in cerebral cortex are initially random on a universally inhibitory background. As cortex grows, connections survive or become less inhibited that are selected by patterns of muscular contraction or sensory receptor stimulation, and the motor- sensory correlations (Spector & Maurer, 2009). Both increases and decreases of connectivity are supported by the evidence, and in theory an appropriate balance increases the efficiency of a learning network (Kados, Henik & Walsh, 2009). There is now evidence from the formation of shape-color associations for such a neural basis for synesthesia at 2-3 months of age which has gone by 8 months (Wagner & Dobkins, 2011).

In an analogous way, within the cultural system at a mind's social basis, the morphemes of a language adapt over history (ter Hark, 2006). Words change in use without confusion about concepts. As a result of such changes at the individual level, the performance and phenomenology of intentions and percepts become increasingly specific, both analytically to distinct features and integrated for each identified entity. For example, if all edible orange colored objects had the smell, taste and texture of the citrus fruit, an orange, and all sweet and sour, fruity smelling and citrus textured objects had the color orange, then orange color might come to taste sour and sweet and/or any material that tasted strongly sweet and sour might look orange in color. This outcome would be modulated by exposure to yellow or green citrus fruit, such as lemons or limes. Most cases of color-taste and color-odor synesthesia do indeed appear to be based on longstanding experience of foods (Spence, Levitan, Shankar & Zampini, 2010; Zampini, Sanabria, Phillips & Spence, 2007).

Nevertheless, distinct biological or social factors could channel the development of some forms of synesthesia. It has been claimed that it may be especially easy for odor to evoke the learned configural norm because of that modality's uniquely wide initial connections around the brain (Stevenson & Tomiczek, 2007). It has been pointed out that regions of the brain critical to the perception of colors and words may be more richly interconnected than other pairs of modalities because they are next to each other, although this suggestion is challenged by the differing localisations of perceived and synesthetically experienced color (Hupe, Bordier & Dojat, 2012). Incidence of synesthesia running in families has been taken to point to genetic factors, but the potential importance of shared environment should not be discounted. The linguistic and material culture clearly is important to some of the specific features that are associated in synesthesia, such as sequences of symbols like 1 to 7 and the names of the first, second or seventh day of the week (Rich *et al*., 2005).

According to early systematic work, a major characteristic of synesthesia is that it is unidirectional (Cytowic, 1995). That would require some extraneous constraint on the formation of a configured norm. For example, a common form of synesthesia is a color evoked by the reading of a letter or the hearing of a musical sound; it would be rare to hear a word or read a piece of music while viewing a color. Nevertheless a case of word-taste synesthesia in both directions has been described in detail (Richer, Beaufils & Poirer, 2011). Perhaps subtler effects in associative learning are involved, such as latent learning or blocking by pre-exposure. Alternatively or as well, unidirectional effects might arise from a difference in salience between the features in the norms for the usual context for each feature.

Discrimination analysis of the synesthetic norm

Potentially subconscious processes in synesthesia have been explored using a Stroop technique (Mills, Boteler & Oliver, 1999). As with the IAT discussed earlier (Greenwald *et al*., 1998), discrimination analysis could give more precise information at the start, in less time for the participant and the investigator.

An outline design for a case of letter-color synesthesia might vary categorical features of the trigger, e.g. E with F, L, I, -, = and ≡, plus a square-cornered 8 and a vertical rectangle, perhaps scaled as number of features added or omitted. Ratings of distances from evoked hue of test patches of different hues could serve as a response. The discrimination between numbers of features by variation in wavelength could be used the characterize interactions between features of the letter E in the color experienced.

Other features of the trigger or the concurrent could be assessed and interacted, such as adjacency in the alphabet or saturation of the color. The hypothesized norm could be tested by adding features that were not part of the synesthesia, such as shape of the colored object and words conceptually related to the word hypothesized to contain the triggering letter.

Development of a biosocial mental life

Lifelong development of a person's causal systems

Mental development throughout life can be analyzed as the building of the causal connections within an individual's discriminative norms to be better afforded by the social and material environment. In recent decades there has been a remarkable acceleration of advances in many areas of the behavioral and cognitive sciences, neuroscience and organismic bioscience, anthropology and other social sciences, and related areas of philosophy. Yet these specialized disciplines, separately and together, have struggled with limited success to construct realistic accounts of the relations between mind and brain, or of the interfacing of individuals' activities and supra-personal communal processes. Two misuses of the concept of causation still slow the growth of a coherent body of knowledge about the achievements of an embodied and acculturated mental life.

One of these misconceptions is that mind and brain interact causally or relate in any lawful way. The alternative presented in this paper is that the distinctive causation within a mind develops throughout life in conjunction with the material causation that extends over the external environment, the body and the brain, and the social causation by which human communities work. None of these three types of causation, nor some fourth type, interconnects the social, material and mental systems. That is, minds, societies and the physical universe are equally real (a neutrally monistic ontology) but require separate sorts of empirical investigation and explanation (a systems pluralist epistemology; cp. Psillos, 2008).

The other confusion is searching for a causal account of development. There is no cause-effect mechanism for the development of a new capacity. The explanation rests in novel exploitation of pre-existing capacities. The placing of a seed in the earth does not cause the plant to grow and flower. The planting permits that member of the species to exploit the affordances of the soil, rain, air and sunlight by the causal processes that are operative at a particular time during its development. Each stage in a plant's growth is characterized by a distinctive network of causation, not by the current state of the plant's appearance, genome or ecology, nor by a discrete set of influences from the previous stage.

In other words, the interdisciplinary science of development is itself non-causal. This fact has sometimes led to the development of a human individual being regarded as fundamentally mysterious. It is unquestionable that minds come into being. Yet it explains nothing to claim merely that the mental emerges from the non-mental. Some account is needed of how mental processes grow out of social and biological processes within the individual.

Unitary growth of embodiment, sociality and mind

We bring up, nourish and educate our offspring intuitively, as our biological and societal ancestry has enabled us to do. The successful development of an intelligent robot, in contrast, has to be explicit about the social context, the hardware and the software that permit the machine to perform. Nevertheless, the digital programs run autonomously, both on the hardware used in central processing and memory, and also in the functioning of the engineered entity within human society (Cangelosi, Metta, Sagerer *et al*., 2010). Equally, psychological development of a natural individual is not determined or explained by the operations of the wetware of the brain or by the social activities of carers and educators, nor by both together.

Rather, the development of a child, or a socially and physically competent robot, builds on the communal and interpersonal functions of the individual's outputs and inputs in word and gesture, and on the physics and physiology of the effectors and sensors. None of this is beyond the relevant sciences, so long as they are integrated in ways appropriate to understanding the development of each particular unity of multiple systems.

Ontogenesis is the classic term in biology for the development of an individual organism. However, that is a purely descriptive concept, encompassing the beginning of any sort of living entity. A stronger term is needed to convey the development of a human person, and of any other animal or machine that proves to be intelligently social. From conception onwards, genomics and culture interact to generate an increasingly autonomous contributor to the biology of the species and the culture of the community (Tomasello &Vaish, 2013). The term autopoiesis has been suggested for the development of an engineered or biological self-operating system (Maturana & Varela, 1980; Varela, Thompson & Rosch, 1991). Another word might be preferable for the much more open-ended development of a person. Autogony literally means self-seeding. That botanical metaphor emphasizes the cycle of sprouting, flowering and reproduction. It also conveys something of the efficacy and part independence of the developed individual, together with the dependence on the germline and the local ecology. Furthermore, autogonic development continues throughout a human life. Not only is the boy child the father of the man; the young man is also the father of the senior citizen, through both environment and genes (Ronald, 2011).

In another metaphor, a mind is sculpted by interactions between genomics and upbringing but that mind increasingly becomes partly self-sculpting. This is not a merely cosmetic operation either. The development of autonomy goes to the center of the person's being (Christman, 1991; Wolf, 1980; cp. Baer, Kaufman & Baumeister, 2008). Habits help to form the individual's dispositions. New thoughts about challenging situations may become some of that person's own pervasive reasons for action. Without some degree of autonomy from genes and environment, there is no scope for an adult to improve, or for fully successful therapy or rehabilitation of someone with serious problems. Cognitive development is lifelong learning.

Developing development science

Non-causal explanation

It is increasingly recognized that individual psychological development needs special sorts of scientific explanation (Karmiloff-Smith, 1998, 2007; Karmiloff-Smith, D'Souza, Dekker *et al*., 2012; Musolino & Landau, 2012; Thomas, Karamenis & Knowland, 2010). Most such work has so far been at an intermediate level of explanation (Hernandez & Blazer, 2006). Distinctive phenomena have been identified. Lifelong interactions of genes and environs (both misconceived as causes) in behavior (misconceived as the phenotypic effect) appear to be channeled or modularized. Sometimes the same capacity develops from multiple routes. Such convergence is well known in biological evolution, such as the camera eye, echolocation and many examples in DNA and protein sequences (Conway Morris, 2005). An example in mental development might be starting to read by phonics alone or word outlines alone. Once the ability to read has matured, both of the original decoding skills are exploited as the task requires of the individual.

A mature science of development will have a specific explanation for the emergence of each particular capacity or incapacity in the individual. Clearly a lot of work has to be done to bring together genomics and the analysis of environmental impact for any condition or competence. Genetic-psychometric survey research complements experimental designs that capture both genetic and environmental variables. That combination can produce surprises. The education-health gradient turns out to arise primarily from traits of temperament rather than habitual cognitive-behavioral processes (Conti & Heckman, 2010). In some developmental disorders, cognitive deficits are often genetic, while physical deficits are often environmental, rather than the other way round as might have been expected (Bishop, 2006).

Usually neither genetic nor environmental determinism is plausible for disorders of mental development. Vulnerability to a disorder comes from a background of interactions among biological and social factors. Interactions between single genes and discrete stressors can be identified when statistical designs are sufficiently sophisticated (McArdle & Prescott, 2010). Examples include some of the syndromes picked out by the anecdotal technique of psychiatric diagnosis (Caspi, Hariri, Holmes *et al*., 2010; Mandelli, Serretti, Marino *et al*., 2007). For instance, infants with the some gene polymorphisms in neurotransmitter systems associated with affective disorders have difficulty in disengaging as soon as most others can from the highly emotive signals which some receive, such as a threatening movement of a face or limb by a carer (Holmboe, Nemoda, Fearon *et al*., 2010; Leppänen, Peltola, Puura *et al*., 2011).

Science from scenarios

The key to full explanation of a dysfunction or of a specific capacity is quantitative characterization of its operation in individuals on particular occasions. Causal analysis of an individual's episode within a scenario is a precision tool for tracking back the content of that biosocial exchange to its start. Much of the work of this sort so far has been limited by reliance on multi-item psychometric scales. Analysis of the causation operative at a particular stage in development requires experimental tests that simulate actual situations encompassed by the single question items in such scales. As always in norm-zeroed discrimination analysis, the outputs and the inputs can be either material or symbolic. Claims that verbal data are unreliable, still made by those who insist on apparently physical responses to physical stimuli, have long since been refuted (Ericsson & Simon, 1993).

An example of how question items could be developed into scenarios is a scale of symptoms of impaired sating of appetite for food that has been developed for use with sufferers from the Prader-Willi syndrome (PWS) of developmental incapacity (Russell & Oliver, 2003). This defect in the expression of a gene often leads to obesity, which results at least in part from difficulty in ending a bout of eating, appearing at about 2 years of age (Holm, Cassidy, Butler *et al.*, 1993). A phenotype of insensitivity to physiological signals remains to be identified, although abnormalities have been reported in hormones related to appetite for food (Haqq, Stadler, Rosenfeld *et al*., 2003). In PWS and some other types of genetically influenced intellectual disability, there is clear sensitivity of eating and other affected behavior to social signals (Oliver, Horsler, Berg *et al*., 2007). A developmental pathway though interactions between genetic and environmental influences on cognition has been proposed (Woodcock, Oliver & Humphreys, 2009a,b). The satiety scale's questions include how often the individual spontaneously performs the tasks of saying *I feel full* or *I still feel hungry*, or of eating more than a standard sized meal.

In order to analyze the mental causation that operates during answers to each or all of these question items, one or two typical contexts for such performance need to be identified, together with the key stimulus and response features in the material and social environment. For instance, vignettes of the finish of the main course of a common meal could vary the amounts of major components such as potatoes and meat (Booth, 2008b; Santos, 1998), how many other people were at the table (De Castro, 1997), and any other factors hypothesized to be important. For each described variant of the scenario, the sufferer or a proven empathic carer would rate likely momentary strength of a sensation of stretch, frequency of pangs of hunger, and size of an additional portion accepted. The rated responses could use vocabulary elicited from sufferers for their thoughts, emotions and desires, about themselves, others and the foods in such a situation. The contribution from each feature to each response can be measured by norm-zeroed discrimination scaling. The resulting greater specificity of characterization of the impairment can be exploited therapeutically. Also, its initial appearance and environmental dependency (e.g. Woodcock *et al*., 2009b) can be tracked back for preventive purposes. Physical and social simulation of the ending of the meal in experimental designs could measure the strength of effect of hormonal actions, a message from a carer, or other experimental variable (cp. Booth, O'Leary *et al*., 2011).

Most obesity is polygenic and ecologically diverse, unlike PWS. In Western data from the middle of the twentieth century, genetic influences on fatness (or leanness) were most strongly expressed in late childhood (Bouchard, Perusse, LeBlanc *et al*., 1988). Considerable attention is currently being paid to the actions of primary carers in early childhood (Birch, Fisher, Grimm-Thomas *et al*., 2001). A number of the items in these research questionnaires refer to particular patterns of parental action affecting the child. Examples include keeping certain foods out of the house (which may have been done before having the child) and speech or action at the table attempting to change the child's eating. Experimental work could be more productive if designs were based on similarities to common situations, not just artificial tests of abstract concepts based on psychometric scale scores.

In adulthood, limited autonomy can be exercised under continuing genetic and environmental influences in the acceptance or refusal of specific types of food or drink on particular occasions, and of opportunities to sit or to walk. Change in choice for reasons of physical health and/or psychological wellbeing may initially be effortful but, as the new norm becomes more precisely afforded by perceived options, read-out into intention can become automatic. The key issue for control of weight is the net effect on exchange of energy between the individual's body and the environment that results from a sustained change in frequency and intensity of a particular pattern of eating, exercise or heat-loss control (Blair, Booth, Lewis & Wainwright, 1989). Once that effectiveness of each commonly maintained pattern has been measured, it becomes critical to know how each change in pattern, supported by that evidence, can become sufficiently automatic to minimize effortful demand on working memory (Baer *et al*., 2008; Lally, Van Jaarsveld, Potts & Wardle, 2010; Lally, Wardle & Gardner, 2011). Scenarios of common lapses from weight-reducing habits within prevalent material and social cultures need to be characterized (Carels, Douglass, Cacciapaglia & O'Brien, 2004). Then the multimodal norm and relative strengths of locally conceptualized environmental factors can be measured in each typical instance of lapsing. That provides the lacking evidence base for both personal and socioeconomic action to reduce and prevent unhealthy long term fatness (Booth & Booth, 2011; Laguna-Camacho, Nouwen & Booth, under review).

The same principles apply to all recurrent activities that have been shown to improve wellbeing or to reduce distress. Life often brings increased involvement in distinct social and material subcultures, including their 'dialects' (D'Andrade, 1995).

Development as learning

The above overview implies that a basic strategy for the science of development is to identify causal processes that are added when performance changes. This strategy can work even when the change looks like a new stage in development. A single additional process can result in a qualitative change in overall performance. Added discrete processes can be sought by comparing observational protocols as soon as possible before and after the change. If mature performance can be explained as a combination of separate causal processes, one or two of those transformations of input into output might be sufficient to account for the earliest performance of that sort.

That approach at first sight may seem to ignore structural change during development. However, a great variety of developed psychological structures, including stages of cognitive growth, have turned out to result from the addition of a further working component to an already functioning set of discrete processes. It takes more than sealing a roof onto an open boat to turn it into a good submarine. Nonetheless, that might be an adequate start.

Whatever the overall structure of a system at any time, there remains the challenge of specifying the components used in its realization. The borderline between architecture and well fitting building blocks is unlikely to be hard and fast. It is a questionable strategy to specify architecture first, because supposedly essential structure has so often dissolved into adapted elements. On the other hand, the attempt to make an initial architectural sketch may help to narrow down options for what the building blocks have to do.

A distinction should be drawn between a simple and uniform type of element in a developing system and what development can do by putting together specific versions of that element which are adapted to the environment in the service of the whole system's performance. The general concept of a discrete causal function transforming incoming information into outgoing information is sufficient to allow the output from one particular element to be coordinated to the input to another specified element, as guided by outputs from and inputs to the whole system. For human development, the capacity for such covert input/output functions has to be immense, in the mind, in the brain and in communal systems such as language. Learning is selection of the activity in such elements that achieves overt input-output transforms which can cope with the current environment, and may even conquer it.

Measuring development

In this approach, the measurement of development relies on tracking back the mental processing from the emergence of a new competence to the latest period of its absence. An individual's psychological development is analyzed as a succession of added competences. First, the performance that has just become possible is characterized from systematic observation. Then differences are identified between that new mental processing and the causation of related performance before the competence was acquired. The search for potential precursors may be more difficult than initially specifying tests of the new competence. The hard graft of developmental psychology is designing investigations that rule a candidate precursor out or in.

Once a difference between new and old competence has been identified, the norms involved can be characterized in more detail by multi-thetic discrimination scaling. This approach complements the classic sequence in developmental psychology of identifying an experimental phenomenon and then exploring the abilities that comprise it by testing single general hypotheses one at a time. Psychological experiments are often designed merely to demonstrate effects that are expected (or not) from a theory that under-specifies the mental mechanisms involved, because relationships between inputs and outputs have not been measured and analyzed.

The characterization of causal elements differing between new and prior processing identifies biological and communal affordances that accommodate the step in development. Hence a novel interaction between the genome and the ecology might be uncovered by use of norm-zeroed discrimination. Interactions already identified from other evidence could be substantiated with full situational specificity, as illustrated earlier.

The approach is highly consonant with several existing lines of evidence regarding cognitive development. Computational approaches have made important contributions. First we shall consider list processing programs. Then a view of connectionist models will be expounded.

Systems of condition-act routines

The early days of artificial intelligence provided some remarkable examples of apparent change in cognitive structure that was explicable as the addition of a new causal process to an already working set of discrete mental mechanisms. The use of scenarios to collect theoretically interpretable anecdotes was crucial to these discoveries.

Piaget (1954, 1970) understood steps in cognitive growth to be changes in mental structure. However, the apparent structural changes between Piagetian stages can be explained as the addition of well adapted routines. Each of these routines converts perceived circumstances into an intention to manipulate the situation in a specific way. Children's solutions to many of the problems that Piaget set to measure the present stage of development can be explained by collections of small numbers of separate routines (Klahr, Langley & Neches, 1987). The set of routines forms a system when the execution of one routine changes environmental affordances in a way that triggers another routine on the list. Cognitive structure is created by the adaption of outputs and inputs between routines, back to the initial conditions of the problem and forward to the actions of a complete solution. Extraneous structure may be imposed so that the system resolves conflicts between routines, such as when incompatible actions are triggered by the same state of the world, two routines oscillate by creating the circumstances that trigger each other, or there is more than one problem to be solved. Nevertheless the main architectural framework is inherent to the routines.

For instance, one of Piaget's tasks is to put a jumble of rods into a row of steadily decreasing length. The movements of children at different stages of solving this problem of length seriation were carefully observed and a detailed simulation of performance at each stage was built from a small number of specific actions in particular circumstances (Young, 1976). Just one extra routine accounted for the shift from an earlier to a later stage. Later work showed that two-thirds of the errors that children made in subtracting one number from another could be explained by their omission of a routine, or their insertion of a routine from another arithmetical task (Young & O'Shea, 1981).

These routines are one sort of re-write rule in computer programming. Each rule can simulate a real system's transition from one state to another. The transitions can be placed in a highly structured recursive network, for example to parse the grammar of an ordinary sentence from its start to its finish (Thorne, Bratley & Dewar, 1968; Woods, 1970). Nevertheless, environmentally adaptive structure can emerge from an active network when it has no pre-set sequencing. For example, a hierarchical structure of activation has been proposed for the diverse types of motivation in sets of particular actions (Hinde, 1969). Nevertheless, the same overall performance can be achieved by a single layer of elements that spread activation to each other, but with deletions of connections keeping apart the groups of output (Ludlow, 1976). The basic mechanism of output from one information transfer function serving as input to another transfer function has been generalized in a determinate mathematics that has many applications in computing and the natural sciences (Petri & Reisig, 2008) and is consistent with the indeterminacies in quantum physics ('t Hooft, 2002).

Learning of responses to stimuli

Associative conditioning

The addition of an adaptive information transfer function is a form of learning in the most general sense of that term. The input conditions correspond to a cue to the successful outcome of an act in response. That is, the development of a new routine is analogous to learning of a conditioned response to a conditional stimulus, or of a stimulus which is specific to a response that is followed by reinforcement. Such learning is investigated by comparing the performance of responses to stimuli before and after training. The tradition of research into associative processes during learning has focused on changes of performance when contingencies in the environment are changed. Cognitive development is equivalent insofar as it can be characterized as increased sensitivity to a contingency that was already present. In this way, growth in competence might be explicable as the acquisition of discrete learned processes.

Doubts about this approach would be justified if the learnt processes were physiological reflexes or responses compelled by biological reinforcers. However, these concepts are misattributions to Pavlov (1927/1960) and Skinner (1953) respectively (cp. Rescorla & Solomon, 1967). Pavlov started as a physiologist studying reflexes but he discovered that learning was necessary to account for the dependence of the reflex response on the context in which it had previously been elicited. The official materialism in post-revolutionary Russia required Pavlov to refer to the mind as higher nervous processes, and to the new responses to stimuli as connections between cortical centers. American behaviorism had its own materialist ontology which persists in use of the term 'response' to equivocate between a pattern of muscular contractions and an action for a reason (Guthrie, 1940; cp., van Dantzig, Pecher & Zwaan, 2008) and using 'stimulus' to conflate physical stimulation of sensors with the mental processes of sensing and perceiving (Hamlyn, 1957). Skinner sought to avoid those errors by operationally defining reinforcement as any consequence of a response that changes subsequent responding of that sort. Hence, reinforcers include broader goals, such as competence itself, and objectives inferred by practical reasoning (prudential or ethical). Such a position becomes incoherent only when it is denied that response-reinforcer relationships are processed by the individuals whose responses are reinforced. Responsible actions are caused by the person's own reasons, such as the belief that particular events are likely to follow a specific action in certain circumstances. That is a freedom which can be dignified without requiring some extraneous owner to pull the rational agent's strings.

Equally, however, learning theorists for their part should acknowledge that improvement in performance, especially in ecologically valid investigations, may come from adaptation of previously existing learned structure, rather than *de novo*. If learning is seen as the updating of previously developed structure, there is less disparity between associationism and traditional analysis of development.

Unfortunately, however, more flexible programming languages and increased computing power have led to the theoretical degeneracy that also afflicts psychophysical laws and non-metric modeling of response patterns in object recognition. Both the structured lists of adapted routines and the parallel processing in randomly connected and non-linearly recursive networks have been shown to develop performance as sophisticated as the perceptual learning of natural scenes and the semantic interpretation of human language (Anderson & Matessa, 1997; Greene & Oliva, 2009; Rumelhart, McClelland & the PDP Research Group, 1987; Suppes, 1968). Yet what has been learned is so opaque in connectionist models that the basic scientific task of testing a specific theoretical explanation is ignored.

Uses of language built from conditioned responses

It has been questioned in philosophy whether there is fundamental difference between a dog learning a specific act in response to a verbal command and an infant first coming to understand what a word refers to (Harrison, 1972). My dog may learn to bring me the correct object whether I say *Fetch me your ball* or *Where is your bone?* A 7 month old infant showed his understanding of the word ‘milk*’* when his mother called out unprompted from another room about his drink of *milk*, by turning to face the cupful that had been placed on the shelf behind him (Booth, 1978a). This example illustrates how the accumulation of anecdotes could constrain theorizing at least as much as the performance of a succession of conventionally designed tests.

The dog has been more or less formally trained. Yet the same environmental contingencies are set up in the informal naming game. It need never have been played with that infant, however, nor any encouragement given to attend to words for objects. The infant turning to face the object illustrates how naming can be based on non-linguistic and even non-symbolic behavior. Eye gaze and head turning can be purely stimulus driven movements. Furthermore sight of such a directed movement is a material affordance to looking at a somewhere on another individual’s line of gaze. Sight of the object can be configured with sound of the word. Indeed, frequency of pointing is correlated across individuals with size of vocabulary early in the second year (Esseily, Jacquet & Fagard, 2011).

Naming has been claimed to be central also to the historical development of language in human culture (Hurford, 1989; Steels, 1997). Nevertheless use of names is only a small part of the workings of language. The picture theory of meaning does not work, even for names (Wittgenstein, 1953). We use words successfully in many other tasks besides stating what is the case (Austin, 1962).

It has been argued recently that learning is based on propositions rather than associations (De Houwer, 2009). This controversy may arise from insufficient distinction between material and symbolic inputs and outputs, rather than from the nature of the causal processes by which an individual connects patterns of information. Animals without language can acquire ‘cognitive maps’ symbolizing their spatial environment (Tolman, 1948), although that interpretation of observed performance has been questioned (Bennett, 1996). An overall associationist account of spatial learning has been constructed (Pearce, 2009). Discrimination scaling shows that differences between material and symbolic stimuli do not bear on the causal processes themselves that convert the past and current information into ongoing overt and covert outputs.

Building a norm

Perception and memory

We have seen that norms do not drive perception and intention 'top-down' any more, or less, than stimuli and responses drive working memory 'bottom-up.' The norm that is active in an individual at any given moment resides in the content of working memory that is afforded by the present environment. The situation may select a matching norm -- that is, one sharing the features that are currently salient. Alternatively, only some less appropriate norms may be available. Processing of such a partly unfamiliar situation may combine existing norms into a new norm or adapt an inadequate norm to be more nearly appropriate in its features and their zero settings (norm points). Indeed, a norm is liable to refinement at any time, in its feature categories and their discrimination units and norm points.

In other words, long-term memory is not an unchanging archive, nor is ongoing perception a flux with no history. The use of past information in the present processing of perception and action is liable to change what is available in working memory on future occasions. False memories can be created (Loftus & Hoffman, 1989; Loftus, Miller & Burns, 1978) or avoided (Knibb & Booth, 2011), depending on how the individual and the cultural and material affordances are allowed to interact. What we call working memory is the running of the most recently learned version of the norm though sensing, conceiving, perception, emotion, intention and thought, thereby updating parameters of the norm. Daydreaming and dreams while asleep run recently active norms without sensing or action. A connection becoming active creates a new past for later activation. The re-used adapting connections are re-consolidated over time (Figure 12) but without at any stage preventing some further use by ongoing perception and intention (Kesner & Conner, 1974; Lee, 2008; Lewis, 1979; Zinkin & Miller, 1967). Conscious or unconscious remembering is the extraction of information from the past by activity in potentially relevant established pathways.

Figure 12 about here

Associative bases

The building of each norm for intention and/or emotion in a particular situation can be explained in terms of known phenomena in associative learning. The addition of a stimulus or response feature to a norm, the setting of the norm value, and the discriminative slope (Weber fraction) of each feature, all have parallels in the conditioning of responses to stimuli (Pavlov, 1927/1960).

The core of the strengthening of features is the learning of a response to a quantitative feature. This prerequisite is distinguishing a difference between categories from identity in category (Wasserman & Young, 2010). With the category of the conditioned stimulus, however, usually a single level is presented during training such as the hue of a light or the pitch of a sound. The learned response is at a peak of vigor and probability at that level of the stimulus but declines on either side. The position of the peak and the slope of its sides are altered by omitting reward from a stimulus of the same category at a different level nearby. The peak moves away from the unrewarded level. The side of the rewarded peak nearer the punished level becomes steeper than the side further away. This can result from summation: the nearer side has increasing inhibition subtracted from the facilitation, making it steeper, while any inhibition subtracted from the farther side decreases, thereby flattening the slope if anything (Bloomfield, 1967; Ghirlanda & Enquist, 2007).

Unfortunately such work on quantities of the learned stimulus has been neglected in favor of categorical stimuli. Nevertheless the basic idea of associative processes accounting for the acquisition of a response to a stimulus has been extended sufficiently to provide an account of each element of a norm as a response controlled by a stimulus, functioning reactively as to Pavlov's conditioned stimulus or with intention as to B.F. Skinner's discriminative stimulus.

Bases of the norm in the culture and the brain

Neglect of the developmental history of an individual's mental causation can lead to serious weaknesses in integrative neuroscience and in cultural analysis. Hence the relations of the workings of the mind to those of either the brain or the culture remain sketchy at best. Ambitious proposals for systematic integration of neuroscience with applied social science disciplines such as education or marketing (e.g., Fischer, Daniel, Immordino-Yang et al., 2007; Revoisé & Morin, 2007) seem highly unrealistic without concrete theory of biosocial mental development based on evidence from norm-zeroed discrimination in real situations.

The first step is relating psychology to neuroscience or to social research is to acknowledge that the learnt norms are distributed through the brain and body and through the material and cultural environs (Booth, 1978b; Clark, 2008).

Sensory receptors do not activate labeled lines into the brain: they extract information that selects its own channels over the real neural networks as specified by current read-out from a norm, or multiple norms (McDermott & Roediger, 1994; Rauss, Schwartz & Pourtois, 2011). The norm for the flavor of a food, for example, is widely distributed through at least temporal, frontal and cingulate regions of cortex (Small & Green, 2012). Motor pools for muscle contractions are activated by the intention norms best matched by current sensory input and other motor output (Bays & Wolpert, 2007; Thakur, Bastian & Hsiao, 2008). Adaptive synapses are distributed as low as needed in sensory afferent pathways (Gilbert & Li, 2012) and the efferents to the spinal motor neurons (Wang, Pillai, Wolpaw & Chen, 2006).

For example, theories of visual object "maintenance" turn out to under-specify both the neural mechanisms and the environmental conditions (Caplovitz *et al*., 2011). That however is in the nature of a psychological theory. The issue is whether the conscious and unconscious mental processes have been adequately specified.

Similarly, the norms for both symbolic and material entities are often highly delocalized in space and time. A particular act by a person at a time and place comes from the individual's life story and the history of family and wider society. An item of food is invested by a cuisine dependent on traditions of agriculture, manufacture, cooking practices, nutritional science and media dissemination. It has been argued that psychological research itself has norms distributed across institutions such as academic subdepartments, books, journals and conferences that are dedicated to supposed sections of the mind, preventing integrated work on any of the domains of daily life for which the norms are built (Rozin, 2006).

Specification of the stimuli

A psychophysical approach to object recognition exposes lack of attention to actual influences on the observed responses. The effective features of the test stimuli are grossly underspecified in terms of the effects of the materials that the individual has learned to recognize. This is illustrated by work on learning about foods and the consequent features of perceptual categories in action on food. The result is serious misunderstandings about the mechanisms by which influences over eating develop and operate, such as sensory preferences and satiety physiology. For examples, choices among food were attributed to their nutrient contents, when the only information available to the chooser was the sensed characteristics which bear no direct relationship to the starch, protein or fat in a food (Booth & Thibault, 2000). Furthermore sensory influences on choice are part of the learned norms for eating in that bodily and social context (Booth, 1985, 2008b, 2009). So far from flavor and texture providing unlearnt reward or pleasure, built into the genes, each configuration of color, odor, taste and touch is an associatively conditioned incentive (Berridge & Robinson, 2003; Booth, 1985), guiding selection in accord with distance of the piece of food from the individual's norm.

Cultural basis of learning

It has been argued that understanding of the mind depends on the analysis of culture and of symbolic communication in particular (Coulter, 1978; Garfinkel, 1967; Forgas, 1982). Approaches vary from solipsistic interpretation of text to the mechanics of political persuasion. In either case, we will only understand language if we also understand the basic principles of what is going on in the mind of an ordinary reader, hearer, speaker, writer and other creator of art, and indeed of a scholar constructing an interpretation of a political event, literary material or a piece of graphic art.

Paradoxically, many scholars of culture have developed a blindness to culture, both the possibility of academic agreement and disagreement, and also the wider society that makes narrative, not mere markings or sounds (D'Andrade, 1995). The lone scholar's own interpretation is treated as the sole reality. Presupposition of any reality to be investigated, whether social, physical or mental, is said to be the evil of 'science' – or, more precisely, of scientism on the model of 17th century physics. The position is impervious to arguments that it is paradoxical. Quite apart from life outside academic deskwork, the text to be interpreted is an existence proof of a reality that constrains interpretation, whether or not there is an author.

Many examples of personal development show mutual informing of individual and culture. As the individual begins to gain independence from familial environment and genes, widely available objects and practices are adopted, inducing new norms. The societal mechanisms of supply and demand create a fashion or establish an enduring change, depending on the numbers who maintain activities in accord with the new norm (Acerbi, Ghirlanda & Enquist, 2012). More fundamentally, every use of a language that adapts a personal norm is liable to change that aspect of the language. The same goes for every other living social institution.

The symbolic processing through which an individual accommodates cultural affordances is unlikely to be distinctively human. It may be deeply rooted in the brains of animals that currently lack any evident culture shared with their conspecifics. For example, propositional mechanisms of learning have been contrasted with associative accounts in other species as well as ours (De Houwer, 2009; Lovibond, 2003). The propositions claimed to control learned performance are representations of the contingences between events (e.g., causal beliefs), rather than direct inputs from events that are causally related. Experimenters who get evidence for propositional learning in non-human subjects (including intelligent machines) are making a fragmentary start on their historical domestication into human culture.

Neural bases of learning

It is widely claimed that we will only understand the mind if we understand the brain. The explanation of private experience, in particular, is supposed to come from better understanding of neural activity. It is unclear, though, whether that means a yet-to-be-specified structuring of connections between neurons or the necessary overall organization magically emerging from synaptic quantum mechanics. The above account of conscious processes and other types of mental performance implies that, to the contrary, we will only understand the brain if we understand the mind.

It is becoming increasingly recognized in psychologically informed neuroscience that the multi-featured categories of perceived and used entities are set up and maintained by learning (Kourtzi & Conner, 2011, e.g. de Yong, Kourtzi & van Ee, 2012). Hence, developmental neuroscience needs specifications of the mental processes of learning. Unfortunately, we have long known enough about the brain to indicate that there is very little if any prospect of locating and characterizing particular learned connections in individuals' brains (Booth, 1967; John, Bartlett, Shinokoc *et al*., 1973). The activity during retrieval of a particular memory would have to be identified in the relevant synapses by time-lagged connectivity analysis (e.g. Roebroeck, Formisano & Goebel, 2005), coupled with double dissociation from another memory (Henson, 2007). An approach that might be more viable is to vary stimulus and response cues that are known to instigate types of processing that produce the response of interest by the individuals whose brain activity is monitored, and then to trace the directions of activation for features and integrations in that norm. At present, patterns of neural response are tracked without sufficient control of stimuli for analysis of the mediating mental processes that are claimed to be embodied in the observed neural activity (e.g., McClure, Li, Tomlin *et al*., 2004; Rolls, 2011). Neither oil nor sucrose simulates the texture of fats or tastes of sugars in foods and drinks. Creaminess and sweetness, for example, are features which are at zero in the diverse norms developed from experience of particular combinations of sensed material constituents and conceptualized cultural attributes of foods and drinks (Booth, 2005; Booth & Freeman, 1993; Gietzen & Aya, 2012).

Phrenological use of imaging tells us nothing about the workings of either the brain or the mind. The individual's mental performance during each brain image must be ascertained, as a start towards measuring doubly dissociated performance processes and directional connectivities (e.g., Imagoglu *et al*., 2012; Zhou, 2009). Then some advance might be made in understanding the neural networking that serves a particular aspect of mental performance, if it is identical across repetitions in individuals who have sufficient commonalities in their learning histories. For example, directional connections between cortical regions indicate that the learned incentive from a particular intensity of taste in a food depends on interaction between gustatory relays and working memory (Ge, Feng, Grabenhorst & Rolls, 2012). Such effects are tied to overall performance by norm-zeroed discrimination analysis (Booth, 1993; Conner *et al*., 1988c).

From measurements to theories of mental development

The above examples illustrate a wide variety of ways in which norm-zeroed discrimination analysis of scenarios could contribute psychological evidence that is essential to advance of the science of development. It would be better to build a new line of investigation on a potentially illuminating anecdote from real life than on an issue generated purely within the research literature. Systematic observation of individual's performance during single incidents identifies situations and their salient features, for categorization by members of the culture. For each major category of incident, inputs need to be specified that appear to vary the outputs (whether or not some output also affects future input). Mediating transformations identified by discrimination modeling can then be tracked backwards and forwards in development.

Once an emerging mental process has been identified, questions about its basis in interactions between genomic expression and acculturating education can be formulated in terms of systems of causal processes within each individual. Such totally disaggregated findings can be combined and compared across appropriate subsets of individuals and situations, to generate fully specified generalizations and differentiations.

Minds as they are

The science of each mind

Personal cognition breaks free from deeply held beliefs and practices that still constrain psychological research and education into the discipline. The approach addresses the nature of the human mind as it is, without intermediation by academic preconceptions, professional practices or meta-scientific commitments. Contrasts of this open-textured theory with other approaches were made above at the points where they are most relevant.

Substantive theoretical content is built from evidence collected in life by the logically simplest instruments currently known. Further theory can be built from comparisons of the mental dynamics within or across individuals and within or across situations. Alternatively, existing psychological theory can be used to construct hypotheses about individuals and/or situations to test on the mental causation actually involved, as it occurs. Examples from the current literature have been given throughout this paper.

Mental, physical and social causation are equally natural

An individual develops as a plurality of distinct causal systems. That is, no causes, laws, entities or events within one sort of system can relate to processes in another sort of system. The philosophical positions that mind is an epiphenomenon of brain, mind is identical to brain, and brain and mind have mechanisms of interaction, are all empty scientifically. It adds nothing conceptual or empirical to the understanding of how a person's mind, body and social role relate to each other to characterize the mind as a function or property of the brain (and body!) or as the exchange among individuals. The philosophical concept of supervenience of mind on brain is increasingly recognized as incoherent. Such ontological materialism (physicalism) dominated Western thought into the present century but is now in its death throes, throttled by a tangle of ambiguities and self-contradictions (Koons & Bealer, 2010).

Human biology provides only a scrappy and highly speculative account of participation in human society by members of our species. Social science and history have generality and particularity that fail to mesh into a generative account of individuals. The human mind should be recognized to be *sui generis* but as natural as the workings of social groups and of organisms and other entities in the material universe.

Awareness of the self, other selves, symbolic and material realities, and one's own unexpressed thoughts, images, feelings and wishes is objective achievement by an individual with a body and a community, as much as the mentation that comprises the performance of overt actions and reactions to observable situations. Private experience, in contrast, transfers those skills of successful engagement with reality to a relinquishing of that possibility of failure. How things seem explicitly carries no commitment as to how things are. Subjective experience cannot be correct or incorrect. Hence it does not provide access to a non-natural world, let alone to certainty about any part of this material, social and mental world. What it is like to be a human individual is the inside view of achievements by a human mind, body and sociality.

Conclusion

In summary, a mind is the conscious and unconscious organizing system of the life of an acculturated and embodied individual. Psychology truly is the science of the soul.

A central task for psychology in the 21st century is to find out the specifics of what is happening in each person, in adequate variety and numbers of instances to resolve issues of principle and to act effectively on problems and opportunities. Psychological research has the responsibility of leadership in that enterprise in both theoretical and practical arenas of human life, as well as the lives of members of other species, and indeed any items of socially and materially competent machinery that may be engineered.

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Table 1. Cell labels for correlating quantities of two events. Presence in Figure 3 is replaced by a level in a higher range (H) of Weber fraction constancy, while absence is replaced by a level in a lower range (L). When only two (ranges of) levels of an event are used, they should be on the same side of the norm in order to disambiguate the estimation of the norm point.

	Event E	
Event F	HL	HH
	LL	LH

<u>Captions to Figures</u> *(duplicated above each Figure from page 99)*

Figure 1. Norm-zeroed discrimination scales. Each of the three graphs (a, b, c) shows the fit to a hyperbola of an individual's judgments in a single session of disparities from preferred salt level (S1: sodium chloride log g / 100 g of plain white bread) in one of the participants reported by Booth *et al*., 1983 (N = 30). Salty rti (R1): the first (and only) response of saltiness relative to ideal (scored 0) towards unacceptably low or high in salt (-50). The participants in panels b and c had the maximum responses furthest from ideal and yet the fitted hyperbola (continuous line) still rises very close to the intersection of the tangents (broken line). The plots are output from the Co-Pro 2.29 tool for modelling personal cognition as described in Booth and Freeman (1993) and this paper.

Figure 2. Unfolded quadratic (Coombs, 1964) versus theoretical hyperbola for: levels of sucrose (log M) in an orange-flavored drink (also varied in level of citric acid) in one session with an individual. Panel a: unfolded quadratic function fitted by eye to data from Figure 5.3 in Booth (1994). Panel b: the same data fitted by CoPro to a hyperbola with center at zero score (see Figure 1). Mismatch to ideal was rated as *always choose* (score = 0) to *never choose* (-10).

Figure 3. Weber's fraction or the fractional half-discriminated disparity: $(S_N – S_O) / S_O$, where the distributions of responses to S_O and S_N have superposed 75th and 25th percentiles, respectively.

Figure 4. Constant concomitance supports the hypothesis that events E and F are causally related. Each 2 x 2 table represents a logically possible occurrence, the top row at the first observation, the second row at the next observation, etc. Some ambiguous possibilities are omitted from the second and subsequent rows. First observed pair of events: 1. Second data pair: 2. Third and fourth: 3, 4.

Figure 5. Constant concomitance with quantitative data, covering higher and lower ranges of a feature of each event. See Table 1. Numerals: sequence of presentation of stimulus levels.

Figure 6. Different causal pathways (channels of information transmission) that can be diagnosed from a stimulus-specific response (R_1) and a more integrative response (R_X) to a stimulus (S_1). S_1 values are processed as distances from a norm that also includes S_2 distances. Each square is a type of mental event, influencing and influenced by other mental events, as indicated by arrows. R_X may be influenced by any of the distinct stimulatory (S), conceptual (R) or descriptive (SR) types of mental process that use information coming from S_1 and/or going to R_1 in the environment.

Figure 7. Types of causal processes within a mind, on one stimulus and two responses afforded in the environment. Panels (a) conceptual (R), (b) descriptive (SR), (c) meaningful (SRR), (d) reasoning, (e) perceptual, (f) stimulatory.

Figure 8. Perceptual processes (SSR) in ratings of mixtures of MSG, salt (NaCl), sugar (sucrose), citric acid and caffeine in tomato juice for similarity to the taste of tomatoes. The panels show norm-zeroed discrimination models of that overall tomato-like taste (R1) by descriptions of (a) NaCl (S2) as salty (R2) MSG (S1), validating the method since MSG and NaCl contain the same sodium ion, (b) citric acid (S4) as sour MSG, (c) MSG (S1) as sourness-lessening (R4) sucrose (S3), and (d) caffeine (S5) as bitter (R5) MSG (S1). Graphs from calculations by the CoPro2.29 program in Java, giving (a) and (b) below the norm point and (c) and (d) above.

Figure 9. Models of a response (R_m) by single types of norm-zeroed discrimination (S, SR, SSR, SRR, RR or R). The black rectangle contains these cognitive-affective-conative mental processes, labelled in the format on the input axis in graphic output from the calculator program (Figures 1, 2b, 7, 9). This diagram shows only one model of each type, e.g. (second downwards) the example of an SSR model is perceiving S_2 under the description of concept R_1 applied to stimulation S_1; others models of the each type have different Sn and/or Rn components. Outside that transparent black box is environmental causation, priding both material and symbolic affordances of stimuli and responses. Arrows point in the hypothesised direction of causation.

Figure 10. Models of the determinants of craving for chocolate (rated response R1) in two individuals, (a) and (b), tested on descriptions of foods varied between chocolate coating and cocoa flavoring (S1), high and low levels of sugar (S2), larger and small portions (S3) and with or without added vitamins (S4). Each portion of food was also rated how chocolatey (R2), sweet (R3), comforting (R4) and healthy (R5) it was. Data pairs are numbered in the sequence of presentation (the same for the two participants). The discrimination scaled calculations constrained models to one type of process. The best model for (a) was SSR ($r^2 = 0.97$), with (b) showing SRR processing ($r^2 = 0.95$). Operator +: discrimination distances added (1-d); ¬ : root sum of squares of distances (between dimensions). The number below each component of the model on the (covert) stimulus axis is its percentage contribution to the r2 value. Both dimensions of craving in (a) and (b) were dominated by sugar, in (a) either as comfortingly filling or healthy chocolate and in (b) as chocolate-like sweet or healthily chocolatey.

Figure 11. Types of causal process within a mind (the translucent black box) during a decision about cooperating with or helping another person on a particular occasion.

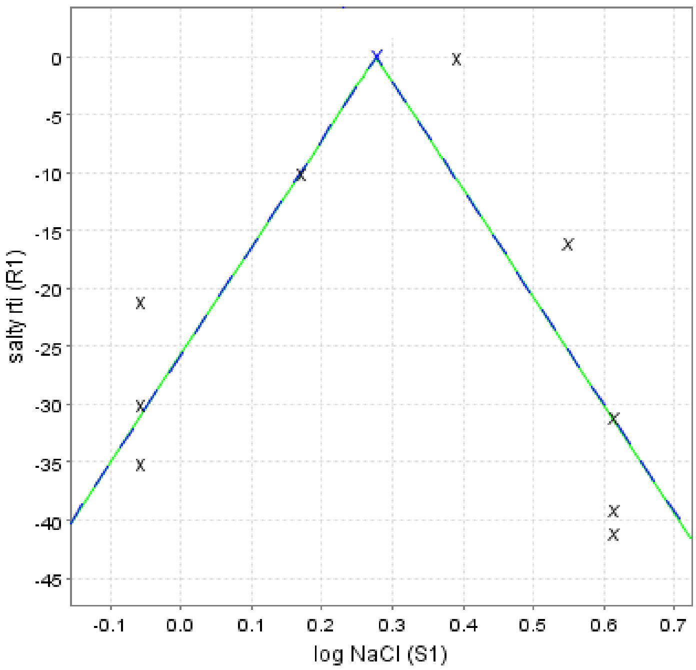
Figure 12. Rise and fall times of overlapping stages of consolidation in the adaptive synapses that are active at a particular moment in working memory. || Latest time for disruption of

retrieval by convulsive current, a short-acting anesthetic or an antibiotic such cycloheximide respectively. Note that reactivation of such a synapse re-starts this sequence of molecular processes. Electroconvulsive shock causes synchronization of synaptic activity, destroying the selectivity of pathway activation. Anesthetics may interrupt the general levels of activation and inhibition, rendering inoperative the threshold mechanism for selecting network paths. Antibiotics disrupt transcription from RNA to the proteins that change the structure of the synapse. (Redrawn from Booth, 1973)

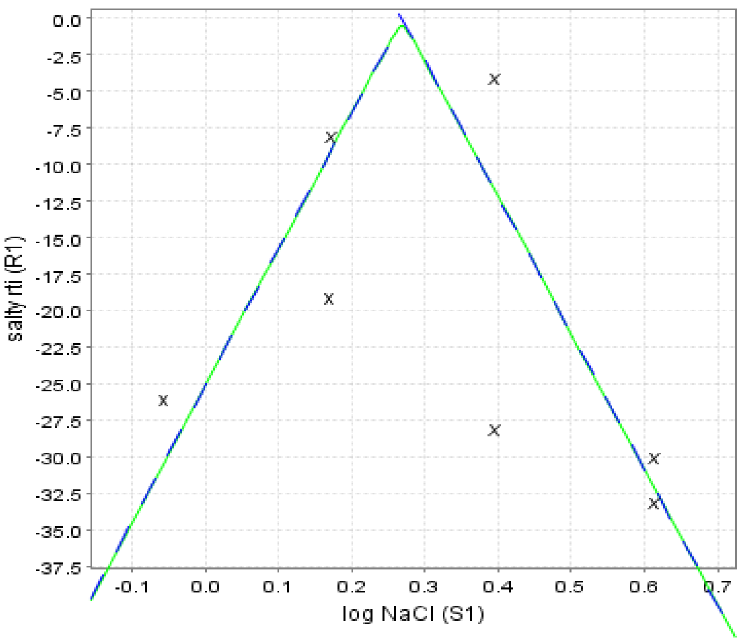
Figures (with captions) for full draft review

[First cited on page 12]
Figure 1. Norm-zeroed discrimination scales. Each of the three graphs (a, b, c) shows the fit to a hyperbola of an individual's judgments in a single session of disparities from preferred salt level (S1: sodium chloride log g / 100 g of plain white bread) in one of the participants reported by Booth *et al*., 1983 (N = 30). Salty rti (R1): the first (and only) response of saltiness relative to ideal (scored 0) towards unacceptably low or high in salt (-50). The participants in panels b and c had the maximum responses furthest from ideal and yet the fitted hyperbola (continuous line) still rises very close to the intersection of the tangents (broken line). The plots are output from the Co-Pro 2.29 tool for modelling personal cognition as described in Booth and Freeman (1993) and this paper,

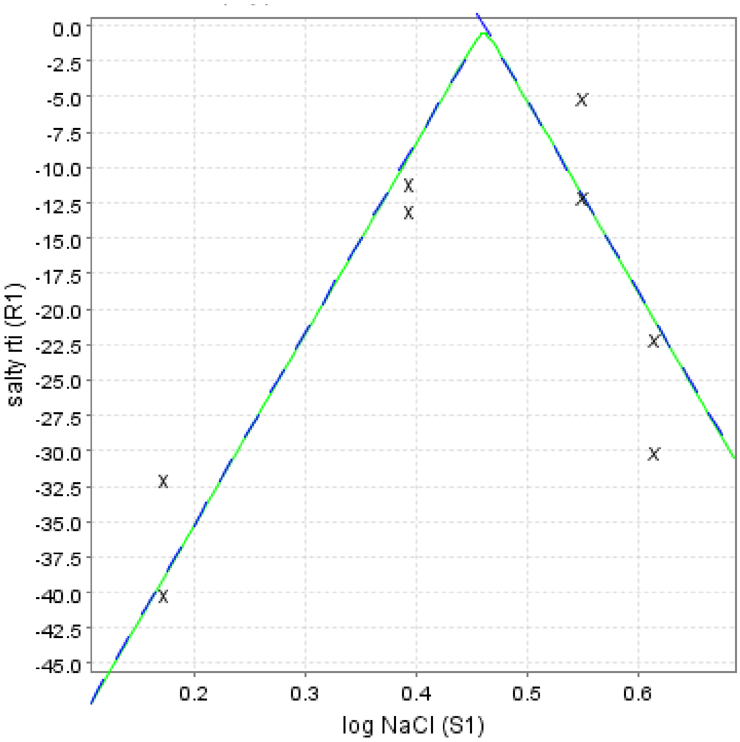
a



b

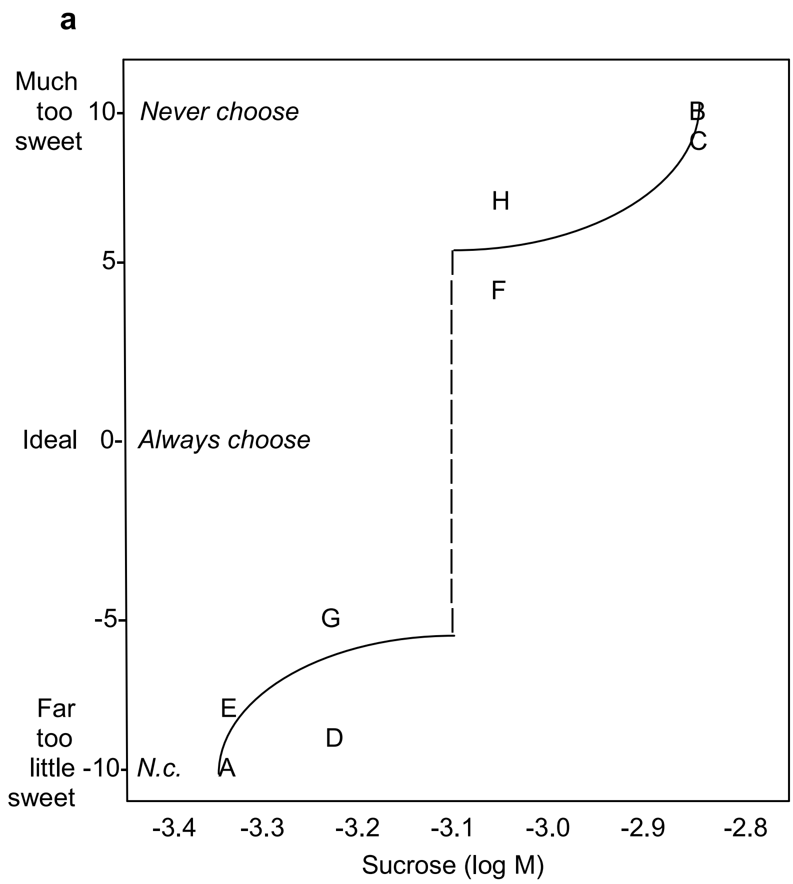

0.0
-2.5
-5.0
-7.5
-10.0
-12.5
-15.0
-17.5
-20.0
-22.5
-25.0
-27.5
-30.0
-32.5
-35.0
-37.5
salty rti (R1)
-0.1
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
log NaCl (S1)

c

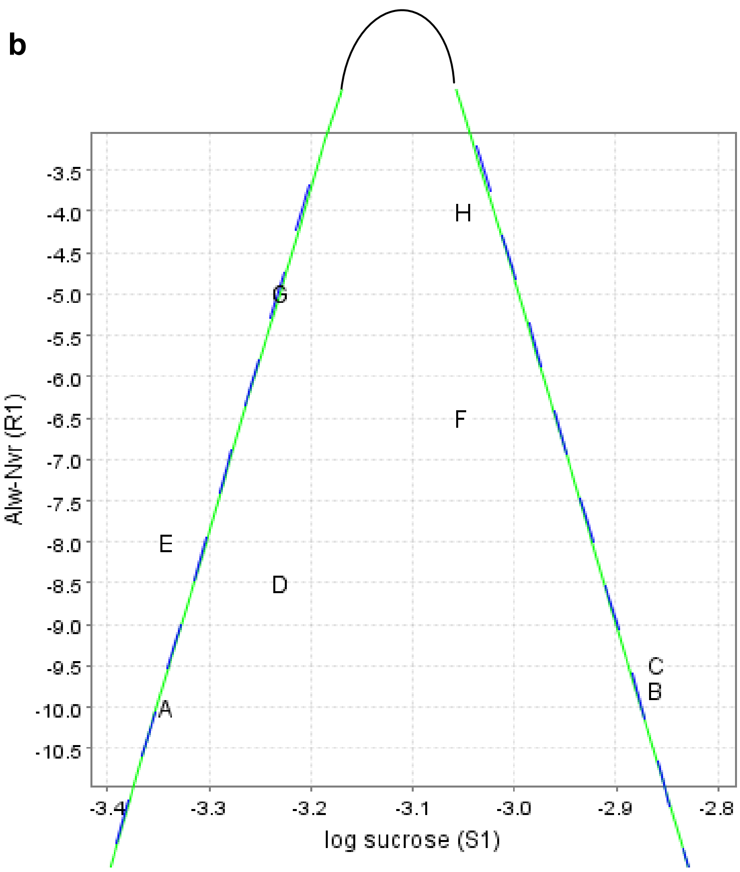

0.0
-2.5
-5.0
-7.5
-10.0
-12.5
-15.0
-17.5
-20.0
-22.5
-25.0
-27.5
-30.0
-32.5
-35.0
-37.5
-40.0
-42.5
-45.0
salty rti (R1)
0.2
0.3
0.4
0.5
0.6
log NaCl (S1)

[Page 13]

Figure 2. Unfolded quadratic (Coombs, 1964) versus theoretical hyperbola for: levels of sucrose (log M) in an orange-flavored drink (also varied in level of citric acid) in one session with an individual. Panel a: unfolded quadratic function fitted by eye to data from Figure 5.3 in Booth (1994). Panel b: the same data fitted by CoPro to a hyperbola with center at zero score (see Figure 1). Mismatch to ideal was rated as *always choose* (score = 0) to *never choose* (-10).

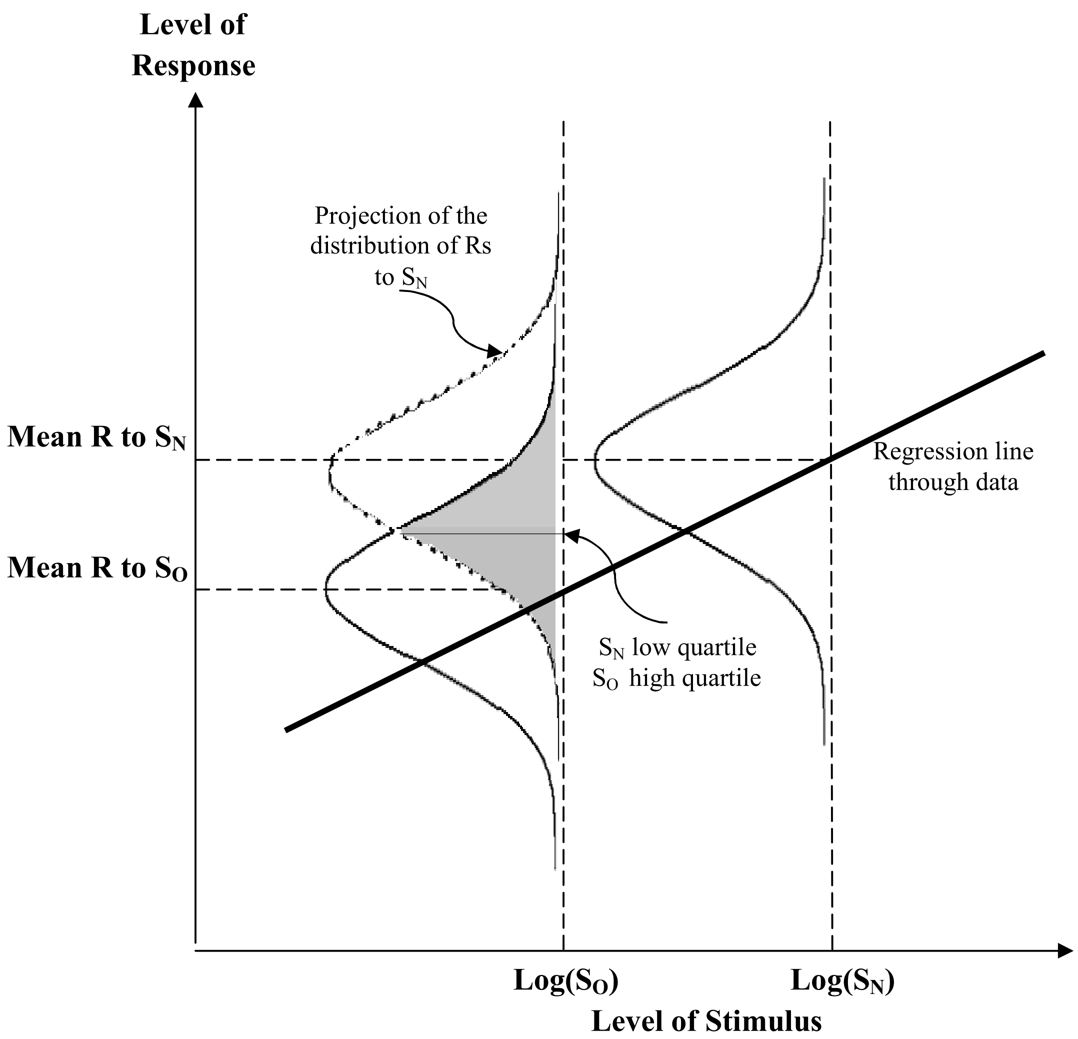


b



Alw-Nvr (R1)
log sucrose (S1)
-3.5
-4.0
-4.5
-5.0
-5.5
-6.0
-6.5
-7.0
-7.5
-8.0
-8.5
-9.0
-9.5
-10.0
-10.5
-3.4
-3.3
-3.2
-3.1
-3.0
-2.9
-2.8
A
B
C
D
E
F
G
H

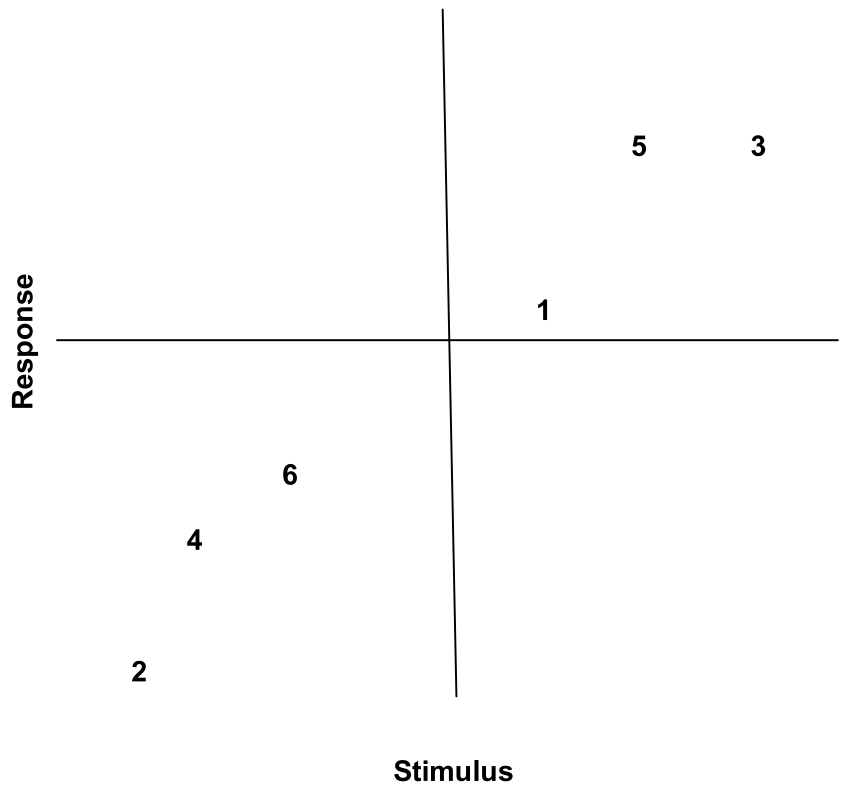
[Page 18] Figure 3. Weber's fraction or the fractional half-discriminated disparity: $(S_N - S_O) / S_O$, where the distributions of responses to S_O and S_N have superposed 75th and 25th percentiles, respectively.



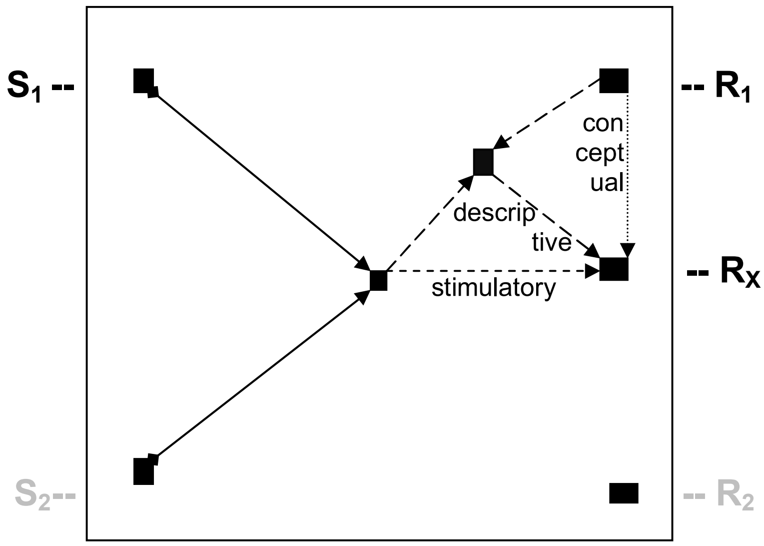
[Page 25] Figure 4. Continued constant concomitance supports the hypothesis that events E and F are causally related. Each 2 x 2 table represents a logically possible occurrence, the top row at the first observation, the second row at the next observation, etc. Some ambiguous possibilities are omitted from the second and subsequent rows. First observed pair of events: 1. Second data pair: 2. Third and fourth: 3, 4.

		Hypothesis supported				Hypothesis undermined			
		Event E		Event E		Event E		Event E	
		Absent	Present	Absent	Present	Absent	Present	Absent	Present
Event	Present		1			1			
F	Absent			1					1
Event	Present		1 2		1	2	1		1
F	Absent			2					2
Event	Present		1 2 3		1 2	3	1 2		1 2
F	Absent			3					3
Event	Present		1 2 4		1 2	4	1 2		1 2
F	Absent	3		3 4		3		3	4

[Page 26] Figure 5. Constant concomitance with quantitative observation (notional data), covering higher and lower ranges of a feature of each event in the sampled context. See Table 1. Numerals: sequence of presentation of stimulus levels.

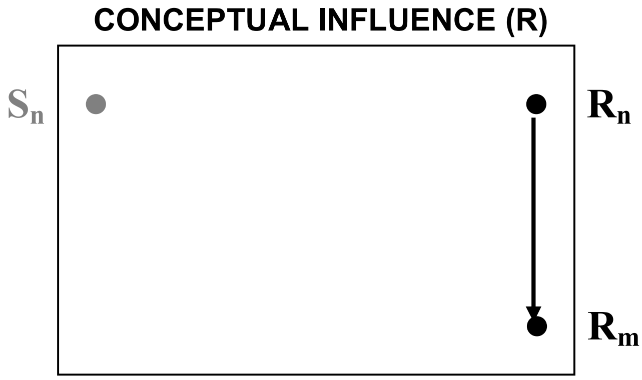


[Page 29] Figure 6. Different causal pathways (channels of information transmission) that can be diagnosed from a stimulus-specific response (R_1) and a more integrative response (R_X) to a stimulus (S_1). S_1 values are processed as distances from a norm that also includes S_2 distances. Each square is a type of mental event, influencing and influenced by other mental events, as indicated by arrows. R_X may be influenced by any of the distinct stimulatory (S), conceptual (R) or descriptive (SR) types of mental process that use information coming from S_1 and/or going to R_1 in the environment.

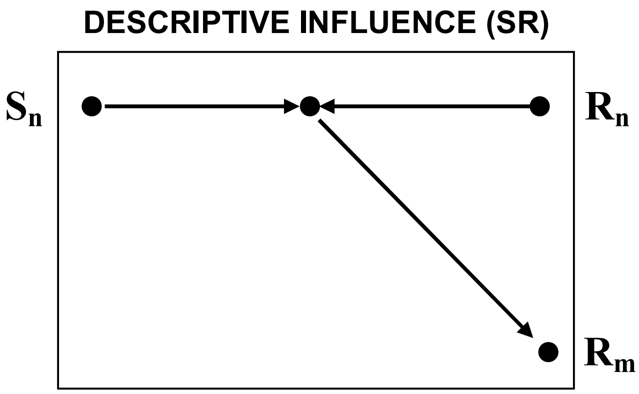


[Page 31]
Figure 7. Types of causal processes within a mind, on one stimulus and two responses afforded in the environment. Panels (a) conceptual (R), (b) descriptive (SR), (c) meaningful (SRR), (d) reasoning, (e) perceptual, (f) stimulatory.

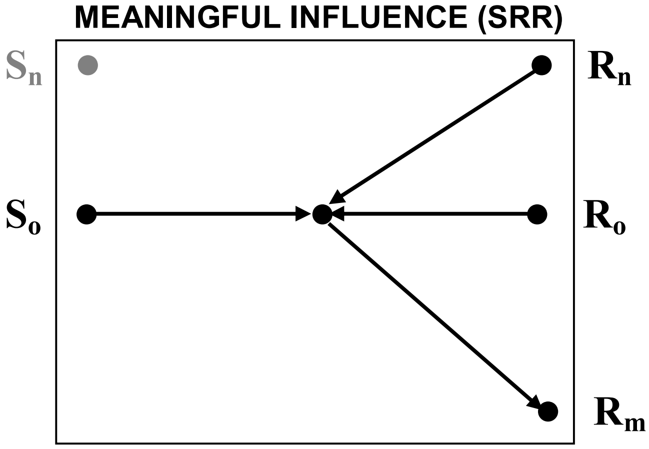
(a)



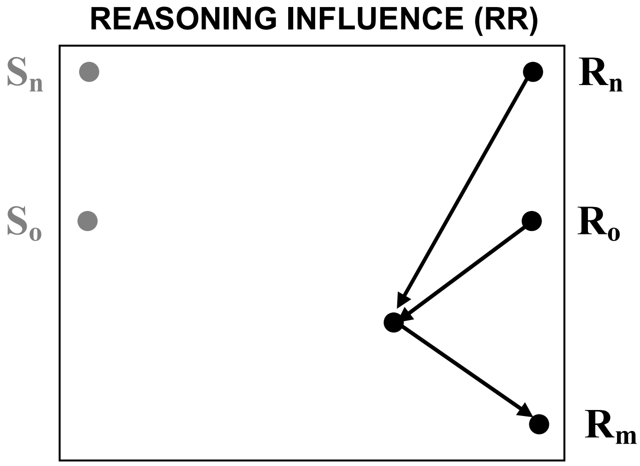
(b)



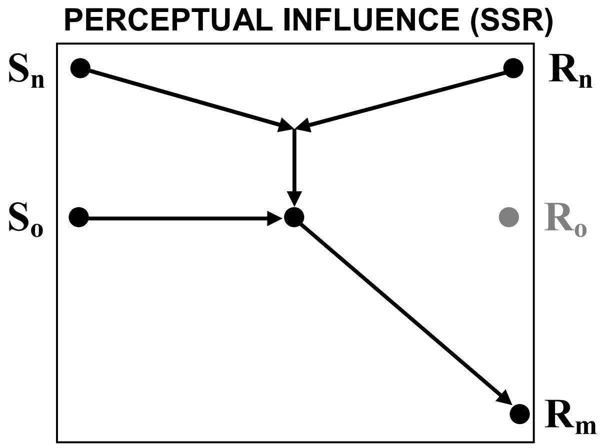
(c)


MEANINGFUL INFLUENCE (SRR)
Sn
Rn
So
Ro
Rm

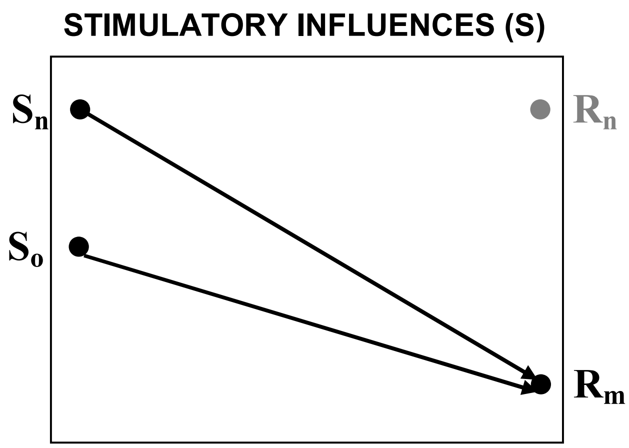
(d)


REASONING INFLUENCE (RR)
Sn
Rn
So
Ro
Rm

(e)

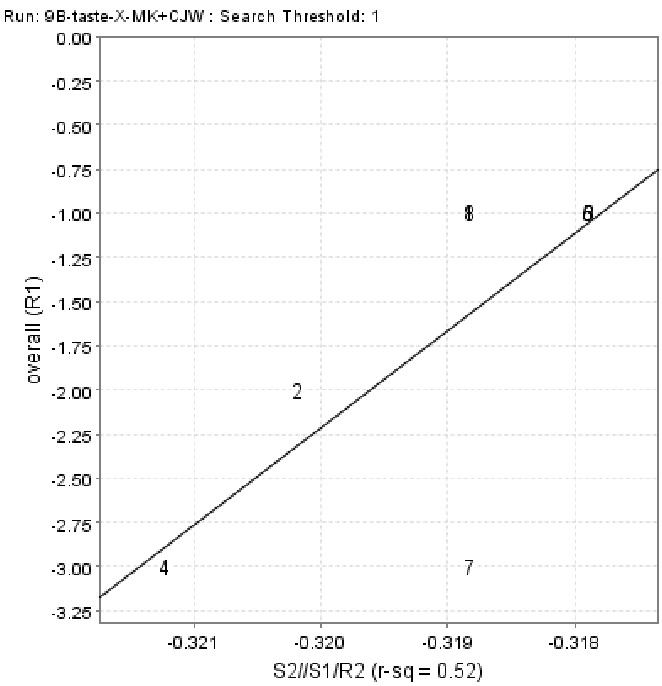

PERCEPTUAL INFLUENCE (SSR)
S_n
R_n
S_o
R_o
R_m

(f)


STIMULATORY INFLUENCES (S)
S_n
R_n
S_o
R_m

[Page 36] Figure 8. Perceptual processes (SSR) in ratings of mixtures of MSG, salt (NaCl), sugar (sucrose), citric acid and caffeine in tomato juice for similarity to the taste of tomatoes. The panels show norm-zeroed discrimination models of that overall tomato-like taste (R1) by descriptions of (a) NaCl (S2) as salty (R2) MSG (S1), validating the method since MSG and NaCl contain the same sodium ion, (b) citric acid (S4) as sour MSG, (c) MSG (S1) as sourness-lessening (R4) sucrose (S3), and (d) caffeine (S5) as bitter (R5) MSG (S1). Graphs from calculations by the CoPro2.29 program in Java, giving (a) and (b) below the norm point and (c) and (d) above.

(a)



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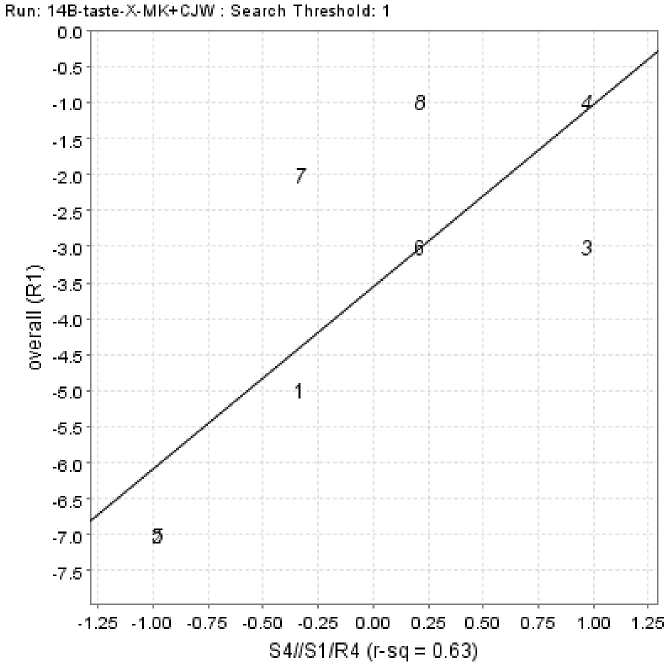
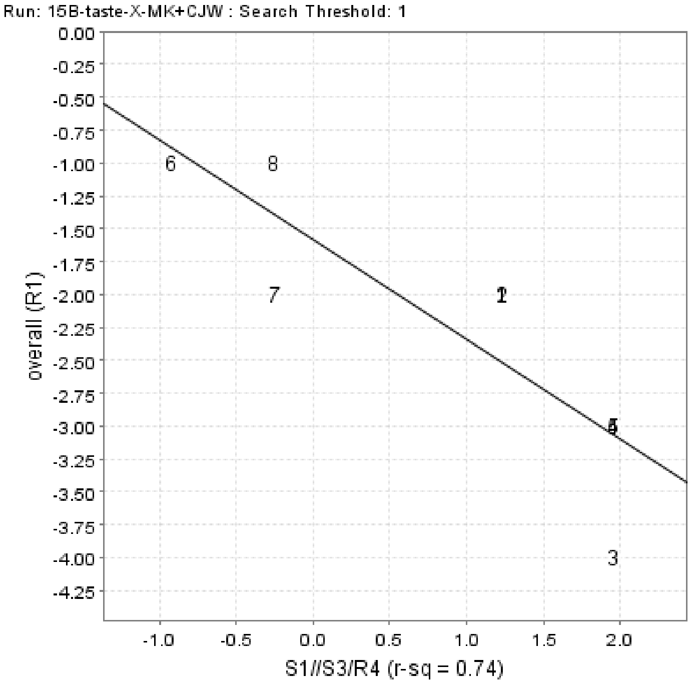
(b)



(c)



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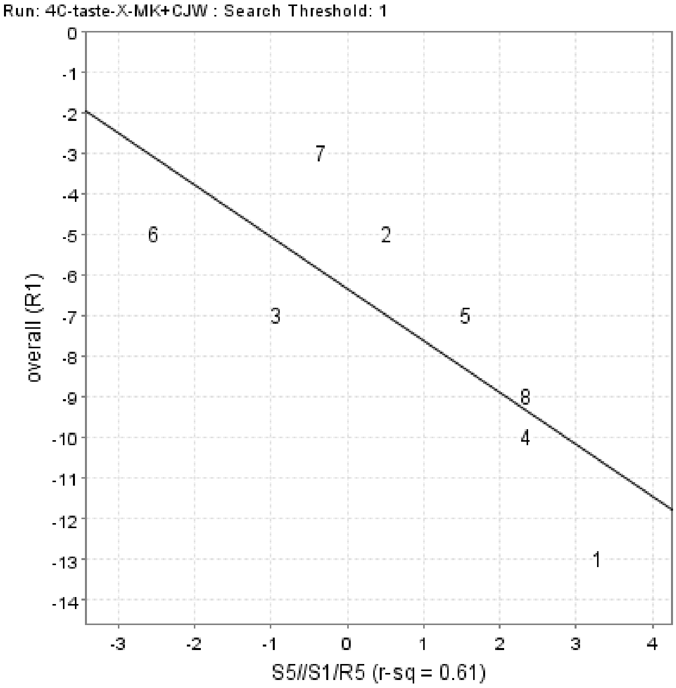
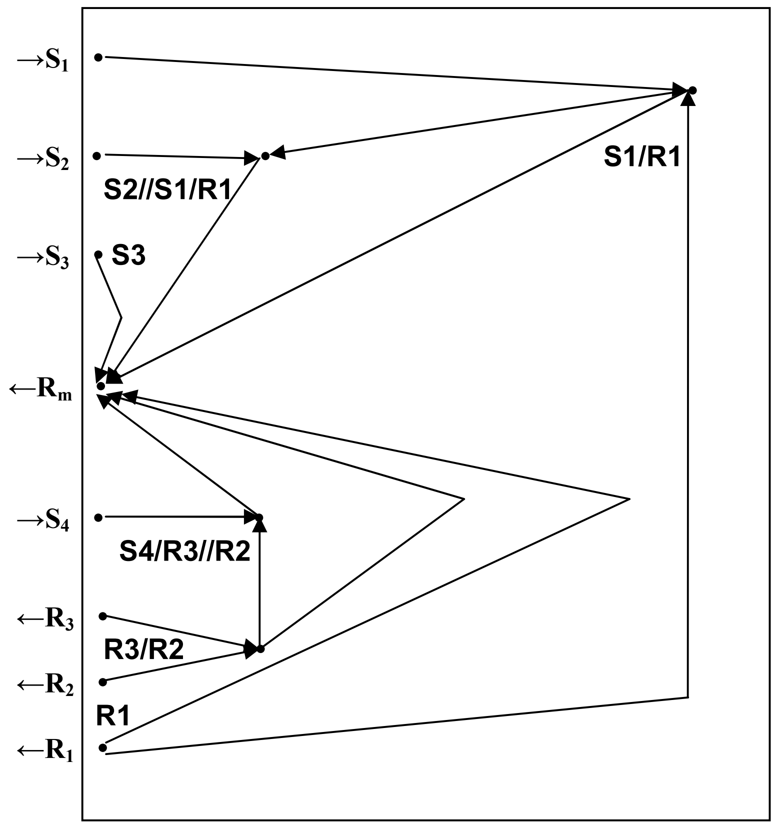
(d)

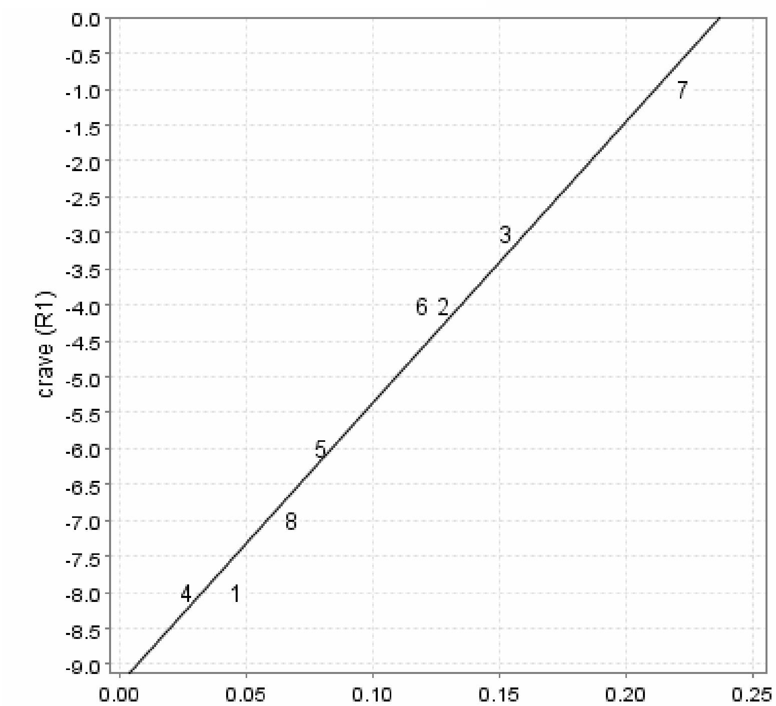

Run: 4C-taste-X-MK+CJW : Search Threshold: 1
overall (R1)
S5//S1/R5 (r-sq = 0.61)
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-3
-2
-1
0
1
2
3
4
7
6
2
3
5
8
4
1

[Page 36] Figure 9. Models of a response (R_m) by single types of norm-zeroed discrimination (S, SR, SSR, SRR, RR or R). The black rectangle contains these cognitive-affective-conative mental processes, labelled in the format on the input axis in graphic output from the calculator program (Figures 1, 2b, 7, 9). This diagram shows only one model of each type, e.g. (second downwards) the example of an SSR model is perceiving S_2 under the description of concept R_1 applied to stimulation S_1; others models of the each type have different Sn and/or Rn components. Outside that transparent black box is environmental causation, priding both material and symbolic affordances of stimuli and responses. Arrows point in the hypothesised direction of causation.



[Page 44] Figure 10. Models of the determinants of craving for chocolate (rated response R1) in two individuals, (a) and (b), tested on descriptions of foods varied between chocolate coating and cocoa flavoring (S1), high and low levels of sugar (S2), larger and small portions (S3) and with or without added vitamins (S4). Each portion of food was also rated how chocolatey (R2), sweet (R3), comforting (R4) and healthy (R5) it was. Data pairs are numbered in the sequence of presentation (the same for the two participants). The discrimination scaled calculations constrained models to one type of process. The best model for (a) was SSR ($r^2 = 0.97$), with (b) showing SRR processing ($r^2 = 0.95$). Operator +: discrimination distances added (1-d); ¬ : root sum of squares of distances (between dimensions). The number below each component of the model on the (covert) stimulus axis is its percentage contribution to the r2 value. Both dimensions of craving in (a) and (b) were dominated by sugar, in (a) either as comfortingly filling or healthy chocolate and in (b) as chocolate-like sweet or healthily chocolatey.

(a)



S2//S3/R5+S3//S2/R5+S4//S3/R5 ¬ S2//S4/R2+S3//S1/R5+S4//S3/R3 (r-sq = 0.97)

30 12 9 25 11 9

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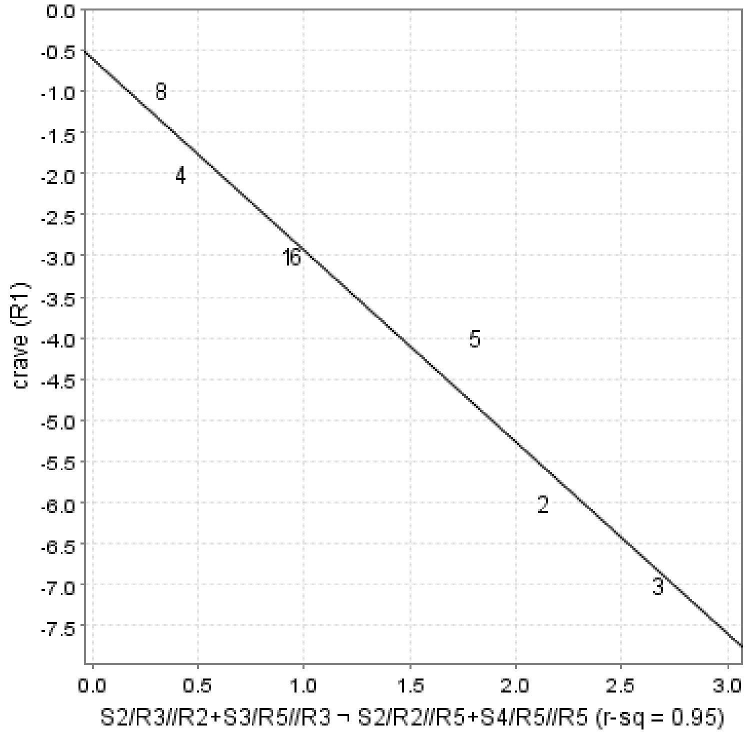
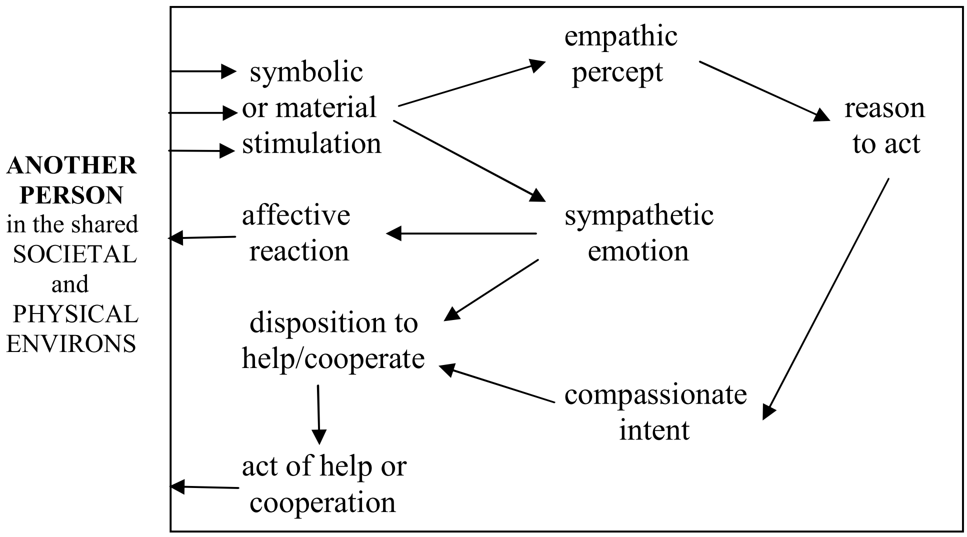
(b)



61 14 20 3

These two panels can be set horizontally across the width of the page, but vertically in a single column is also OK.

[Page 45] Figure 11. Types of causal process within a mind (the translucent black box) during a decision about cooperating with or helping another person on a particular occasion.



[Page 65] Figure 12. Rise and fall times of overlapping stages of consolidation in the adaptive synapses that are active at a particular moment in working memory. || Latest time for disruption of retrieval by convulsive current, a short-acting anesthetic or an antibiotic such cycloheximide respectively. Note that reactivation of such a synapse re-starts this sequence of molecular processes. Electroconvulsive shock causes synchronization of synaptic activity, destroying the selectivity of pathway activation. Anesthetics may interrupt the general levels of activation and inhibition, rendering inoperative   the threshold mechanism for selecting network paths. Antibiotics disrupt transcription from RNA to the proteins that change the structure of the synapse. (Redrawn from Booth, 1973)

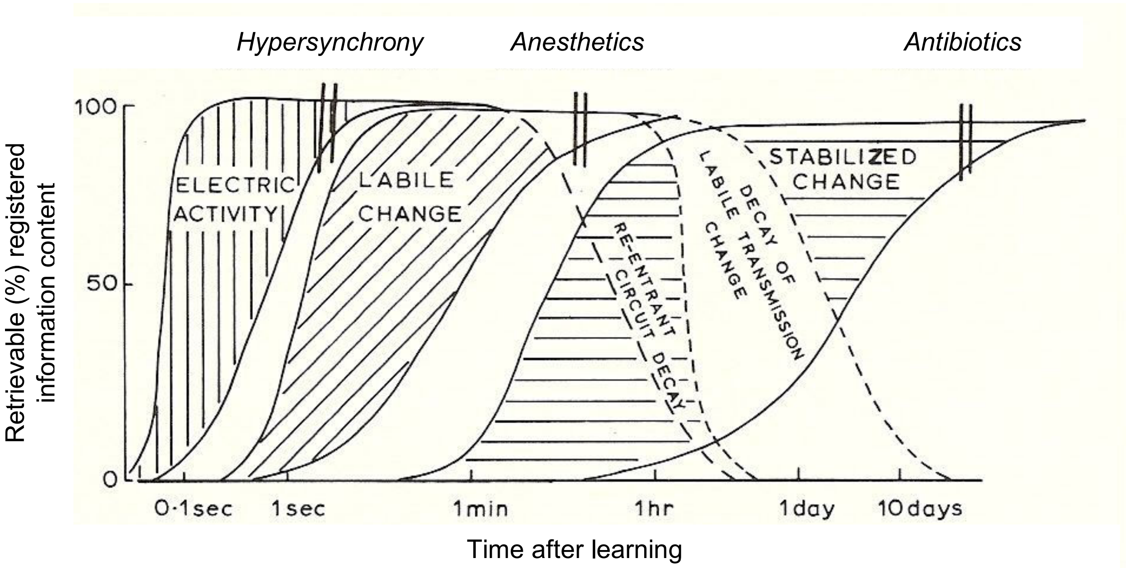


Figure X? – the Cone